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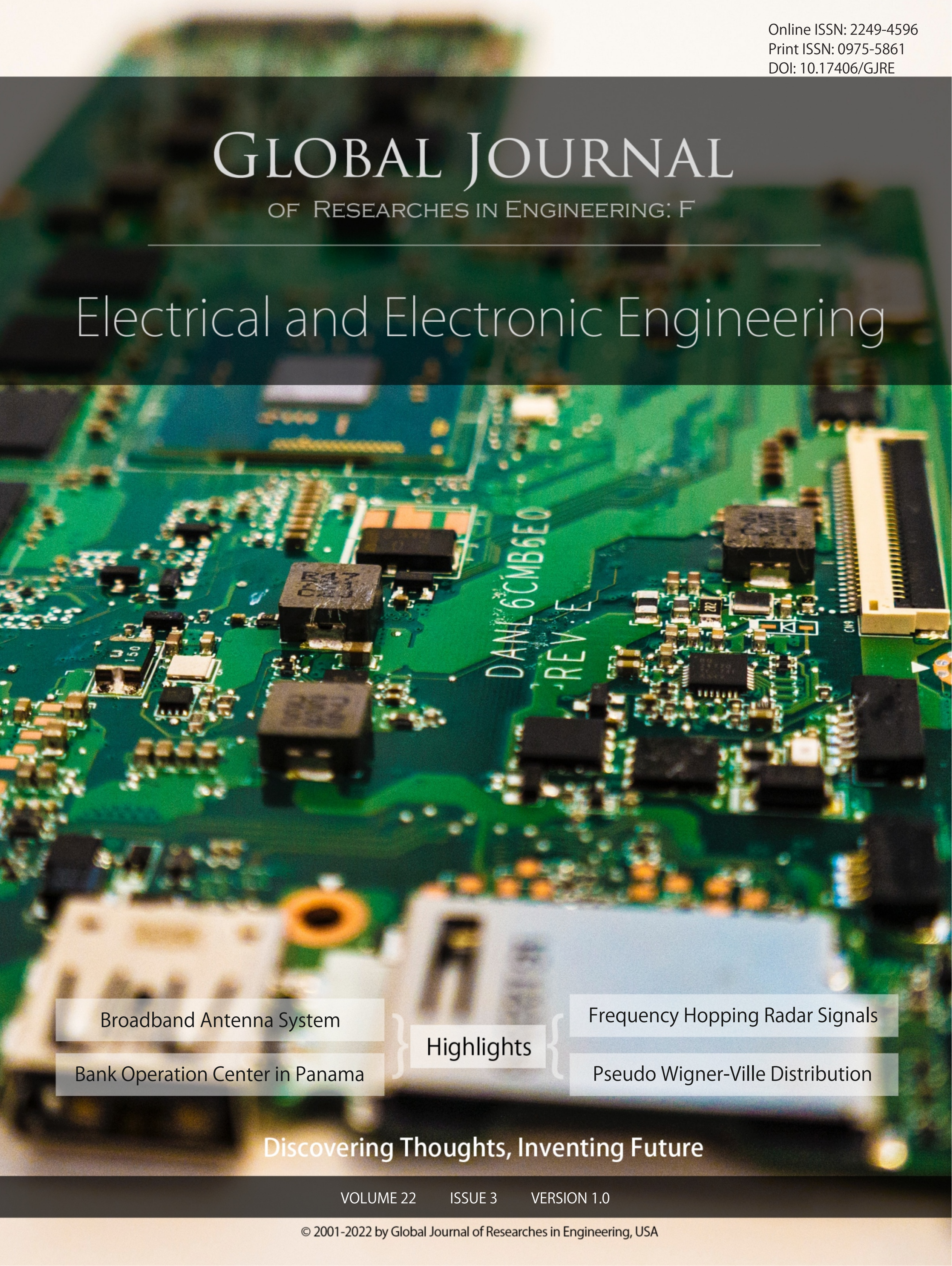

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of Researches in Engineering: F

Electrical and Electronic Engineering

Highlights

- Broadband Antenna System
- Bank Operation Center in Panama
- Frequency Hopping Radar Signals
- Pseudo Wigner-Ville Distribution

Discovering Thoughts, Inventing Future

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A Unique Method for Detecting and Characterizing Low Probability of Intercept Frequency Hopping Radar Signals by means of the Wigner-Ville Distribution and the Reassigned Smoothed Pseudo Wigner-Ville Distribution

By Daniel L. Stevens

Abstract- Low probability of intercept radar signals, which are may times difficult to detect and characterize, have as their goal 'to see but not be seen'. Digital intercept receivers are currently moving away from Fourier-based techniques and toward classical time-frequency techniques for analyzing low probability of intercept radar signals. This paper brings forth the unique approach of both detecting and characterizing low probability of intercept frequency hopping radar signals by employing and comparing the Wigner-Ville Distribution and the Reassigned Smoothed Pseudo Wigner-Ville Distribution. Four-component frequency hopping low probability of intercept radar signals were analyzed. The following metrics were used for evaluation: percent error of: carrier frequency, modulation bandwidth, modulation period, and time-frequency localization. Also used were: percent detection, lowest signal-to-noise ratio for signal detection, and relative processing time.

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Daniel L. Stevens

Abstract- Low probability of intercept radar signals, which are may times difficult to detect and characterize, have as their goal 'to see but not be seen'. Digital intercept receivers are currently moving away from Fourier-based techniques and toward classical time-frequency techniques for analyzing low probability of intercept radar signals. This paper brings forth the unique approach of both detecting and characterizing low probability of intercept frequency hopping radar signals by employing and comparing the Wigner-Ville Distribution and the Reassigned Smoothed Pseudo Wigner-Ville Distribution. Four-component frequency hopping low probability of intercept radar signals were analyzed. The following metrics were used for evaluation: percent error of: carrier frequency, modulation bandwidth, modulation period, and time-frequency localization. Also used were: percent detection, lowest signal-to-noise ratio for signal detection, and relative processing time. Experimental results demonstrate that overall, the Reassigned Smoothed Pseudo Wigner-Ville Distribution produced more accurate characterization metrics than the Wigner-Ville Distribution. An improvement in performance could potentially translate into saved equipment and lives.

I. Introduction

A low probability of intercept (LPI) radar that uses frequency hopping techniques changes the transmitting frequency in time over a wide bandwidth to prevent an intercept receiver from intercepting the waveform. The frequency slots are chosen from a frequency hopping sequence, which is unknown to the intercept receiver, thereby giving the radar the advantage in processing gain over the intercept receiver. The frequency sequence appears random to the intercept receiver, thereby making it nearly impossible for the intercept receiver to follow the changes in frequency [PAC09]. This, in turn, prevents a jammer from jamming the transmitted frequency [ADA04]. Frequency hopping radar performance depends only slightly on the code used, given that certain properties are met. This allows for a larger assortment of codes, making it even more difficult to intercept.

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Time-frequency signal analysis includes the analysis and processing of signals which have time-varying frequency content. These signals are best represented by a time-frequency distribution [PAP94], [HAN00], which displays how the energy of the signal is distributed over the two-dimensional time-frequency plane [WEI03], [LIX08], [OZD03]. The processing of the signal may then exploit the features produced by the concentration of the signal energy in two dimensions (time and frequency), as opposed to one dimension (either time or frequency) [BOA03], [LIY03]. Since noise has a tendency to spread out uniformly over the time-frequency domain, whereas signals tend to concentrate their energies within limited time intervals and limited frequency bands; the local SNR of a noisy signal can be improved simply by using time-frequency analysis [XIA99]. Also, an intercept receiver can increase its processing gain through the implementation of time-frequency signal analysis [GUL08].

Time-frequency distributions can be extremely beneficial for the visual interpretation of signal dynamics [RAN01]. An experienced operator will be better able to detect a signal and extract its parameters by examining the time-frequency distribution [ANJ09].

a) Wigner-Ville Distribution (WVD)

One of the most prominent time-frequency distribution members is the WVD. The WVD satisfies a great number of desirable mathematical properties. It is always real-valued, it preserves time and frequency shifts, and it satisfies marginal properties [AUG96], [QIA02]. The WVD is a transformation of a continuous time signal into the time-frequency domain, and is computed by correlating the signal with a time and frequency translated version of itself, making the WVD bilinear. In addition, the WVD exhibits the highest signal energy concentration in the time-frequency plane

[WIL06]. By using the WVD, an intercept receiver can come close to having a processing gain near the LPI radar's matched filter processing gain [PAC09]. The WVD also contains cross term interference between every pair of signal components, which may limit its applications [GUL07], [STE96], and which can make the WVD time-frequency representation hard to interpret, especially if the components are numerous or close to each other, and the more so in the presence of noise [BOA03]. This lack of readability can in turn translate into decreased signal detection and parameter extraction metrics, potentially placing the intercept receiver signal analyst in harm's way.

The WVD of a signal $x(t)$ is given in equation (1) as:

$$W_x(t,f) = \int_{-\infty}^{+\infty} x(t+\frac{\tau}{2})x^*\left(t-\frac{\tau}{2}\right)e^{-j2\pi f\tau}\,d\tau \quad (1)$$

or equivalently in equation (2) as:

$$W_x(t,f) = \int_{-\infty}^{+\infty} X(f+\frac{\xi}{2})X^*\left(f-\frac{\xi}{2}\right)e^{j2\pi\xi t}\,d\xi \quad (2)$$

b) Reassigned Smooth Pseudo Wigner-Ville Distribution (RSPWVD)

The original idea of reassignment was introduced in an attempt to improve the Spectrogram [OZD03]. As with any other bilinear energy distribution, the Spectrogram is faced with the trade-off between the reducing the misleading interference terms and sharpening the localization of the signal components.

We can define the Spectrogram as a two-dimensional convolution of the WVD of the signal by the WVD of the analysis window, as in equation (3):

$$S_x(t,f;h) = \iint_{-\infty}^{+\infty} W_x(s,\xi)W_h(t-s,f-\xi)ds\,d\xi \quad (3)$$

Therefore, the distribution reduces the interference terms of the signal's WVD, but at the expense of time and frequency localization. But a closer look at equation (3) shows that $W_h(t-s,f-\xi)$ delimits a time-frequency domain at the vicinity of the (t,f) point, inside which a weighted average of the signal's WVD values is performed. The key point of the reassignment principle is that these values really have no reason to be symmetrically distributed around (t,f), the geometrical center of this domain. Their average should not be assigned at this point, but rather at the center of gravity of this domain, which is more representative of the local energy distribution of the signal [AUG94]. Using a mechanical analogy, the local energy distribution $W_h(t-s,f-\xi)W_x(s,\xi)$ (as a function of s and ξ) can be considered as a mass distribution, and it is much more accurate to assign the total mass (i.e. the Spectrogram value) to the center of gravity of the domain rather than to its geometrical center. Another way to look at it is this: the total mass of an object is assigned to its geometrical center, an arbitrary point which, except in the very specific case of a homogeneous distribution, has no reason to suit the actual distribution. A more meaningful choice is to assign the total mass of an object, as well as the Spectrogram value, to the center of gravity of their respective distribution [BOA03].

This is exactly how the reassignment method proceeds: it moves each value of the Spectrogram computed at any point (t,f) to another point $(\hat{t},\hat{f})$ which is the center of gravity of the signal energy distribution around (t,f) (see equations (4) and (5)) [LIX08]:

$$\hat{t}(x;t,f) = \frac{\iint_{-\infty}^{+\infty} s\,W_h(t-s,f-\xi)W_x(s,\xi)ds\,d\xi}{\iint_{-\infty}^{+\infty} W_h(t-s,f-\xi)W_x(s,\xi)ds\,d\xi} \quad (4)$$

$$\hat{f}(x;t,f) = \frac{\iint_{-\infty}^{+\infty} \xi\,W_h(t-s,f-\xi)W_x(s,\xi)ds\,d\xi}{\iint_{-\infty}^{+\infty} W_h(t-s,f-\xi)W_x(s,\xi)ds\,d\xi} \quad (5)$$

leading to a reassigned Spectrogram (equation (6)), whose value at any point (t',f') is the sum of all the Spectrogram values reassigned to this point:

$$S_x^{(r)}(t',f';h) = \iint_{-\infty}^{+\infty} S_x(t,f;h)\delta(t'-\hat{t}(x;t,f))\delta\left(f'-\hat{f}(x;t,f)\right)dt\,df \quad (6)$$

An interesting property of this new distribution is that it also uses the phase information of the STFT, and not just its squared modulus, as in the Spectrogram. It uses this information from the phase spectrum in order to sharpen the amplitude estimates in both time and frequency. This can be seen from the following expressions of the reassignment operators:

$$\hat{t}(x;t,f) = -\frac{d\Phi_x(t,f;h)}{df} \quad (7)$$

$$\hat{f}(x;t,f) = f + \frac{d\Phi_x(t,f;h)}{dt} \quad (8)$$

where $\Phi_x(t,f;h)$ is the phase of the STFT of x : $\Phi_x(t,f;h) = \arg\ F_x$ (t, f; h)). But these expressions (equations (7) and (8)) do not lead to an efficient implementation, and have to be replaced by equations (9) (local group delay) and (10) (local instantaneous frequency):

$$\hat{t}(x;t,f) = t - \Re\left\{\frac{F_x(t,f;T_h)F_x^*(t,f;h)}{\left|F_{x(t,f;h)}\right|^2}\right\} \quad (9)$$

$$\hat{f}(x;t,f) = f - \Im\left\{\frac{F_x(t,f;D_h)F_x^*(t,f;h)}{\left|F_{x(t,f;h)}\right|^2}\right\} \quad (10)$$

where $T_h(t) = t \times h(t)$ and $D_h(t) = \frac{dh}{dt}(t)$. This leads to an efficient implementation for the Reassigned Spectrogram without explicitly computing the partial derivatives of phase. The Reassigned Spectrogram may thus be computed by using 3 STFTs, each having a different window (the window function h; the same window with a weighted time ramp t*h; and, the derivative of the window function h with respect to time (dh/dt)). Reassigned Spectrograms are therefore very computationally efficient to implement.

Since time-frequency reassignment is not a bilinear operation, it does not permit a stable reconstruction of the signal. In addition, once the phase information has been used to reassign the amplitude coefficients, it is no longer available for use in reconstruction. For this reason, the reassignment method has received limited attention from engineers, and its greatest potential seems to be where reconstruction is not necessary, that is, where signal analysis is an end unto itself.

One of the most important properties of the reassignment method is that the application of the reassignment process to any distribution of Cohen's class, theoretically yields perfectly localized distributions for chirp signals, frequency tones, and impulses. This is one of the reasons that the reassignment method was chosen for this paper as a signal processing technique for analyzing LPI radar waveforms such as the frequency hopping waveforms (which can be viewed as multiple tones).

In order to resolve the classical time-frequency analysis deficiency of cross-term interference, a method needs to be used which reduces cross-terms, which the reassignment method does.

The reassignment principle for the Spectrogram allows for a straight-forward extension of its use for other distributions as well [HIP00], including the WVD. If we consider the general expression of a distribution of the Cohen's class as a two-dimensional convolution of the WVD, as in equation (11):

$$C_x(t,f;\Pi) = \iint_{-\infty}^{+\infty} \Pi(t-s, f-\xi) W_x(s,\xi) ds\, d\xi \quad (11)$$

replacing the particular smoothing kernel $W_h(u,\xi)$ by an arbitrary kernel $\Pi(s,\xi)$ simply defines the reassignment of any member of Cohen's class (equations (12) through (14)):

$$\hat{t}(x;t,f) = \frac{\iint_{-\infty}^{+\infty} s\, \Pi(t-s,f-\xi)W_x(s,\xi)ds\, d\xi}{\iint_{-\infty}^{+\infty} \Pi(t-s,f-\xi)W_x(s,\xi)ds\, d\xi} \quad (12)$$

$$\hat{f}(x;t,f) = \frac{\iint_{-\infty}^{+\infty} \xi\, \Pi(t-s,f-\xi)W_x(s,\xi)ds\, d\xi}{\iint_{-\infty}^{+\infty} \Pi(t-s,f-\xi)W_x(s,\xi)ds\, d\xi} \quad (13)$$

$$C_x^{(r)}(t',f';\Pi) = \iint_{-\infty}^{+\infty} C_x(t,f;\Pi)\delta\left(t' - \hat{t}(x;t,f)\right)\delta\left(f' - \hat{f}(x;t,f)\right) dt\, df \quad (14)$$

The resulting reassigned distributions (which include the RSPWVD) efficiently produce a reduction of the interference terms provided by a well adapted smoothing kernel. In addition, the reassignment operators $\hat{t}(x;t,f)$ and $\hat{f}(x;t,f)$ are very computationally efficient [AUG95].

II. Methodology

The methodologies detailed in this section describe the processes involved in obtaining and comparing metrics between the classical time-frequency analysis techniques of the Wigner-Ville Distribution and the Reassigned Smoothed Pseudo Wigner-Ville Distribution for the detection and characterization of low probability of intercept frequency hopping radar signals.

The tools used for this testing were: MATLAB (version 8.3), Signal Processing Toolbox (version 6.21), and Time-Frequency Toolbox (version 1.0). All testing was accomplished on a desktop computer.

Testing was performed for the 4-component frequency hopping waveform. Waveform parameters were chosen for academic validation of signal processing techniques. Due to computer processing resources they were not meant to represent real-world values. The number of samples for each test was chosen to be 512, which seemed to be the optimum size for the desktop computer. Testing was performed at three different SNR levels: 10dB, 0dB, and the lowest SNR at which the signal could be detected. The noise added was white Gaussian noise, which best reflects the thermal noise present in the IF section of an intercept receiver [PAC09]. Kaiser windowing was used, when windowing was applicable. 100 runs were performed for each test, for statistical purposes. The plots included in this paper were done at a threshold of

5% of the maximum intensity and were linear scale (not dB) of analytic (complex) signals; the color bar represents intensity. The signal processing tools used for each task were the Wigner-Ville Distribution and the Reassigned Smoothed Pseudo Wigner-Ville Distribution.

The frequency hopping (prevalent in the LPI arena [AMS09]) 4-component signal had parameters of: sampling frequency=5KHz; carrier frequencies=1KHz, 1.75KHz, 0.75KHz, 1.25KHz; modulation bandwidth=1KHz; modulation period=.025sec.

After each particular run of each test, metrics were extracted from the time-frequency representation.

The different metrics extracted were as follows:

1) Relative Processing Time: The relative processing time for each time-frequency representation.

2) Percent Detection: Percent of time signal was detected. Signal was declared a detection if any portion of each of the 4 signal components exceeded a set threshold (a certain percentage of the maximum intensity of the time-frequency representation). Threshold percentages were determined based on visual detections of low SNR signals (lowest SNR at which the signal could be visually detected in the time-frequency representation). Based on the above methodology, thresholds were assigned as follows for the signal processing techniques used for this paper: WVD (50%); RSPWVD (50%).

For percent detection determination, these threshold values were included in the time-frequency plot algorithms so that the thresholds could be applied automatically during the plotting process. From the threshold plot, the signal was declared a detection if any portion of each of the signal components was visible (see Figure 1).

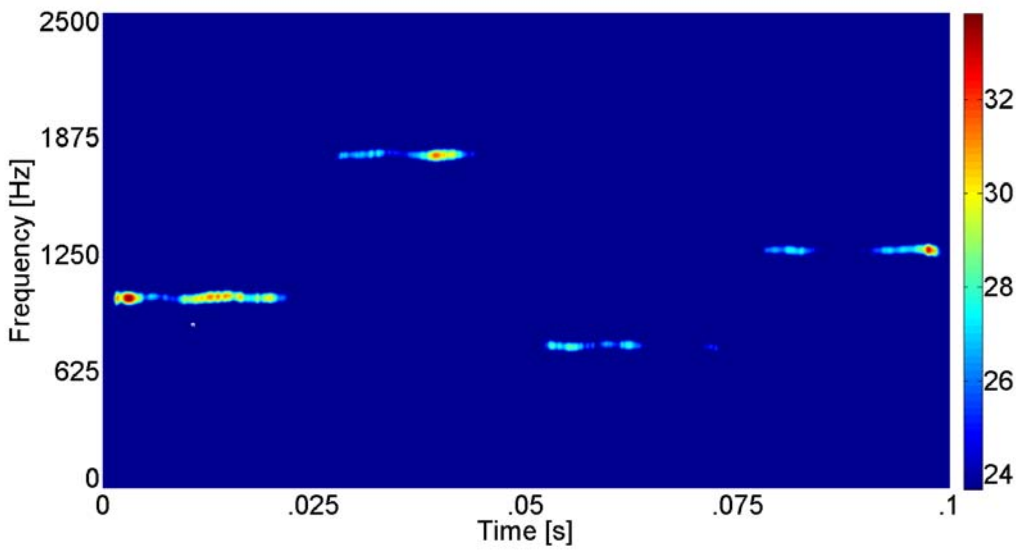

Figure 1: Percent detection (time-frequency). Time-frequency distribution for a 4-component frequency hopping signal (512 samples, SNR=10dB). From this threshold plot, the signal was declared a (visual) detection because at least a portion of each of the 4 FSK signal components was visible

3) Carrier Frequency: The frequency corresponding to the maximum intensity of the time-frequency representation for the frequency hopping waveforms.

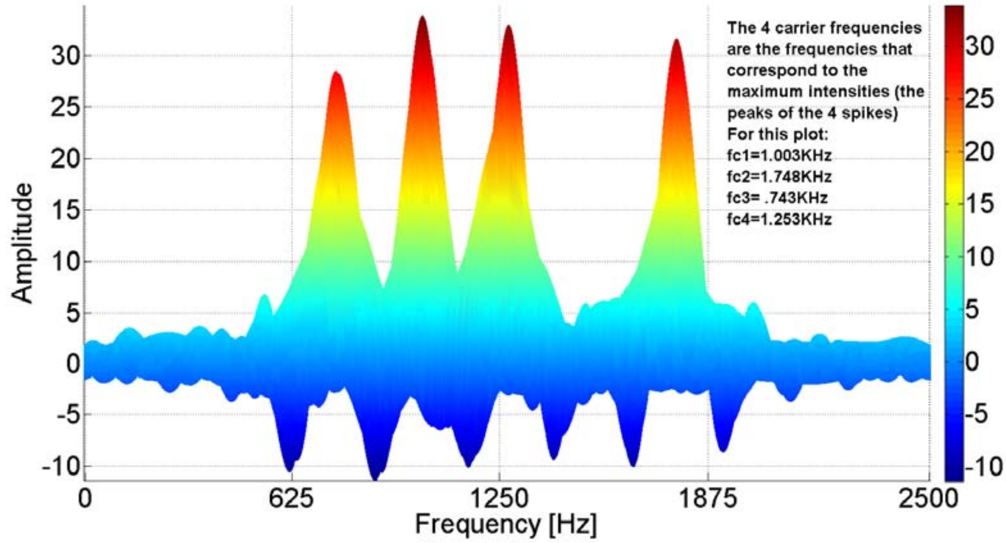

Figure 2: Determination of carrier frequency for a 4-component frequency hopping signal (512 samples, SNR=10dB). From the frequency-intensity (y-z) view of the time-frequency distribution, the 4 maximum intensity values (1 for each carrier frequency) are manually determined. The frequencies corresponding to those 4 max intensity values are the 4 carrier frequencies (for this plot fc1=1003 Hz, fc2=1748Hz, fc3=743Hz, fc4=1253Hz)

4) Modulation Bandwidth: Distance from highest frequency value of signal (at a threshold of 20% maximum intensity) to lowest frequency value of signal (at same threshold) in Y-direction (frequency).

The threshold percentage was determined based on manual measurement of the modulation bandwidth of the signal in the time-frequency representation. This was accomplished for ten test runs of each time-frequency analysis tool (WVD and RSPWVD). During each manual measurement, the max intensity of the high and low measuring points was recorded. The average of the max intensity values for these test runs was 20%. This was adopted as the threshold value, and is representative of what is obtained when performing manual measurements. This 20% threshold was also adapted for determining the modulation period and the time-frequency localization (both are described below).

For modulation bandwidth determination, the 20% threshold value was included in the time-frequency plot algorithms so that the threshold could be applied automatically during the plotting process. From the threshold plot, the modulation bandwidth was manually measured (see Figure 3).

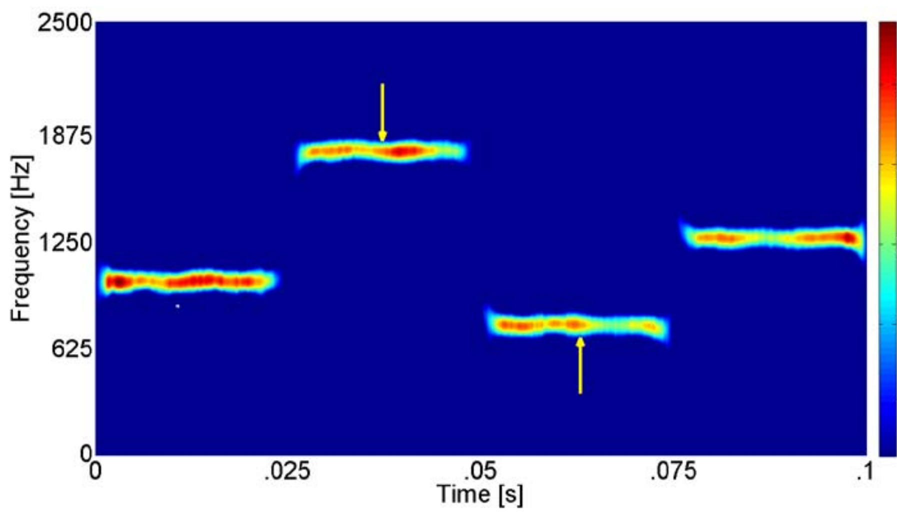

Figure 3: Modulation bandwidth determination for a 4-component frequency hopping signal (512 samples, SNR=10dB) with threshold value automatically set to 20%. From this threshold plot, the modulation bandwidth was measured manually from the highest frequency value of the signal (top yellow arrow) to the lowest frequency value of the signal (bottom yellow arrow) in the y-direction (frequency)

5) Modulation Period: From Figure 4 (which is at a threshold of 20% maximum intensity), the modulation period is the manual measurement of the width of each of the 4 frequency hopping signals in the x-direction (time), and then the average of the 4 signals is calculated.

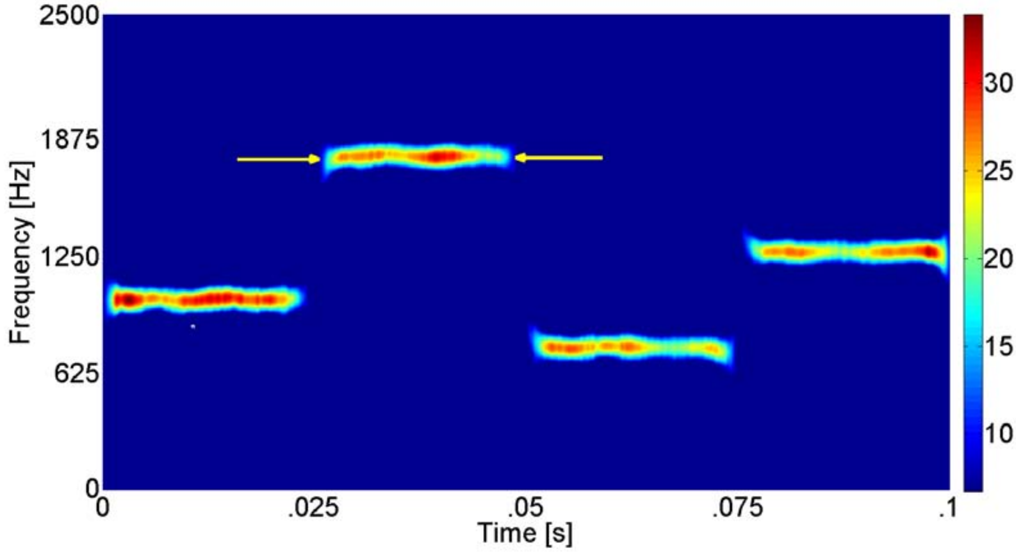

Figure 4: Modulation period determination for a 4-component frequency hopping signal (512 samples, SNR=10dB) with threshold value automatically set to 20%. From this threshold plot, the modulation period was measured manually from the left side of the signal (left yellow arrow) to the right side of the signal (right yellow arrow) in the x-direction (time). This was done for all 4 signal components, and the average value was determined

6) Time-Frequency Localization: From Figure 5, the time-frequency localization is a manual measurement (at a threshold of 20% maximum intensity) of the 'thickness' (in the y-direction) of the center of each of the 4 frequency hopping signal components, and then the average of the 4 values are determined. The average frequency 'thickness' is then converted to: percent of the entire y-axis.

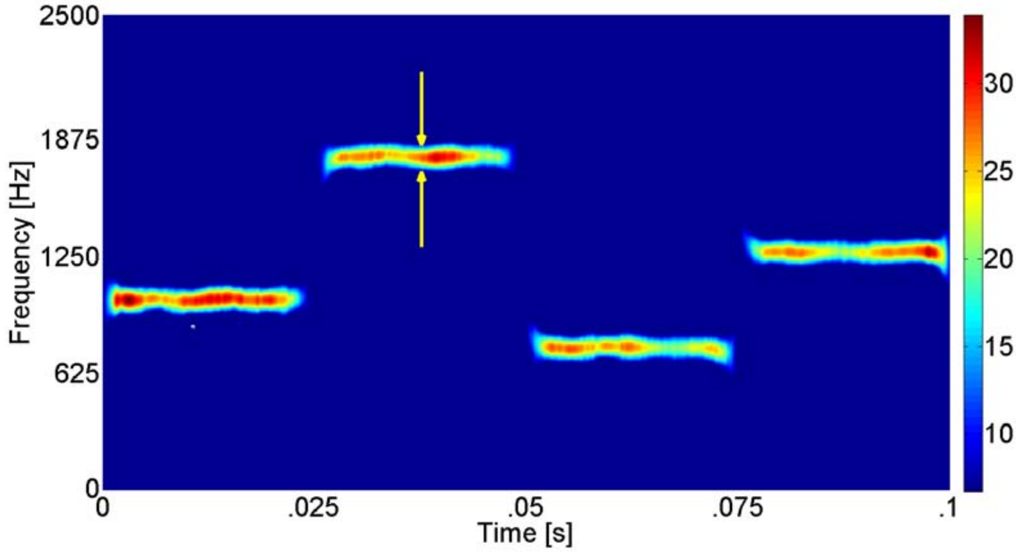

Figure 5: Time-frequency localization determination for a 4-component frequency hopping signal (512 samples, SNR=10dB) with threshold value automatically set to 20%. From this threshold plot, the time-frequency localization was measured manually from the top of the signal (top yellow arrow) to the bottom of the signal (bottom yellow arrow) in the y-direction (frequency). This frequency 'thickness' value was then converted to: % of entire y-axis

7) Lowest Detectable SNR: The lowest SNR level at which at least a portion of each of the signal components exceeded the set threshold listed in the percent detection section above.

For lowest detectable SNR determination, these threshold values (WVD (50%); RSPWVD (50%)) were included in the time-frequency plot algorithms so that the thresholds could be applied automatically during the plotting process. From the threshold plot, the signal was declared a detection if any portion of each of the 4 signal components was visible. The lowest SNR level for which the signal was declared a detection is the lowest detectable SNR.

The data from all 100 runs for each test was used to produce the actual, error, and percent error for each of these metrics listed above.

The metrics from the WVD were then compared to the metrics from the RSPWVD. By and large, the RSPWVD outperformed the WVD, as will be shown in the results section.

III. Results

Table 1 presents the overall test metrics for the two classical time-frequency analysis techniques used in this testing (WVD versus RSPWVD).

Table 1: Overall test metrics (average percent error: carrier frequency, modulation bandwidth, modulation period; average: time-frequency localization-y (as percent of y-axis), percent detection, lowest detectable snr, relative processing time) for the two classical time-frequency analysis techniques (WVD versus RSPWVD)

Parameters	WVD	RSPWVD
Carrier Frequency	0.21%	0.12%
Modulation Bandwidth	6.07%	4.72%
Modulation Period	16.51%	6.05%
Time-Frequency Localization-Y	2.14%	1.28%
Percent Detection	90.2%	94.1%
Lowest Detectable SNR	-2.0dB	-3.0dB
Relative Processing Time	0.682s	0.023s

From Table 1, the RSPWVD outperformed the WVD in average percent error: carrier frequency (0.12% vs. 0.21%), modulation bandwidth (4.72% vs. 6.07%), modulation period (6.05% vs. 16.51%), and time-frequency localization (y-direction) (1.28% vs. 2.14%); and in average: percent detection (94.1% vs. 90.2%), lowest detectable SNR (-3.0dB vs. -2.0dB) and average relative processing time (0.023s vs. 0.682s).

Figure 6 shows comparative plots of the WVD vs. the RSPWVD (4-component frequency hopping) at SNRs of 10dB (top), 0dB (middle), and lowest detectable SNR (-2.0dB for WVD and -3.0dB for RSPWVD) (bottom).

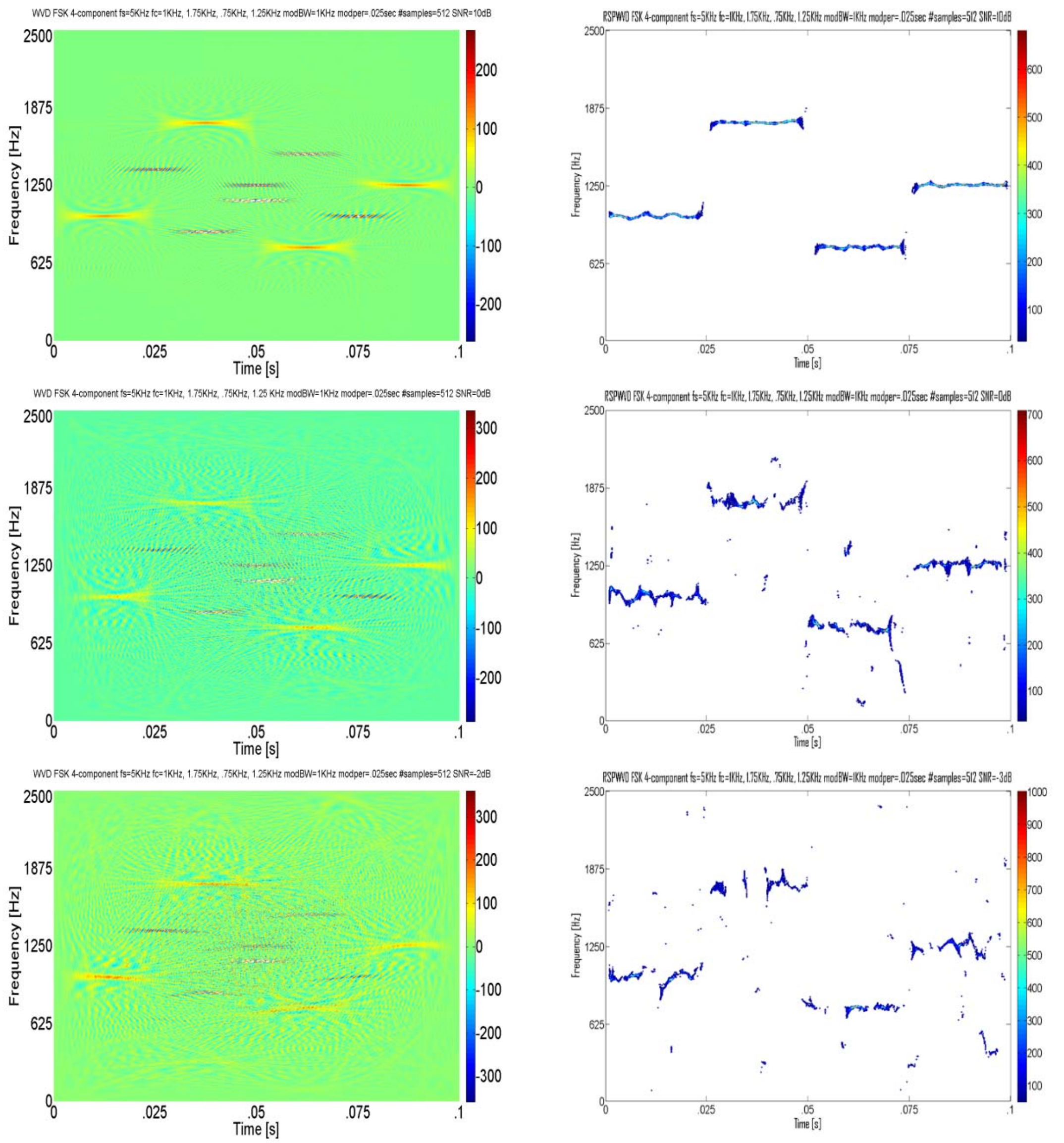

Figure 6: Comparative plots for a4-component frequency hopping low probability of intercept radar signals (WVD (left-hand side) vs. RSPWVD (right-hand side)). The SNR for the top row is 10dB, for the middle row is 0dB, and for the bottom row is the lowest detectable SNR(-2dB for WVD and -3dB for RSPWVD). The RSPWVD signals are more localized than the WVD signals. In addition, the WVD does have a cross-term half-way between each signal, which, to the untrained eye, could be misinterpreted as a 'cross-term false positive' (the 6 blue 'false signals') – the more so as the SNR gets lower

IV. Discussion

This section will elaborate on the results from the previous section.

From Table 1, the RSPWVD outperformed the WVD in average percent error: carrier frequency (0.12% vs. 0.21%), modulation bandwidth (4.72% vs. 6.07%), modulation period (6.05% vs. 16.51%), and time-frequency localization (y-direction) (1.28% vs. 2.14%); and in average: percent detection (94.1% vs. 90.2%), lowest detectable SNR (-3.0dB vs. -2.0dB) and average relative processing time (0.023s vs. 0.682s). These results are the result of the RSPWVD signal being a more localized signal than the WVD signal, along with the fact that the WVD signal has cross-term interference, which the RSPWVD doesn't have.

The RSPWVD might be used in a scenario where you need good signal localization in a fairly low SNR environment, in a short amount of time. The RSPWVD would be preferred over the WVD in virtually every scenario, based on the metrics obtained.

V. Conclusions

Digital intercept receivers, whose main job is to detect and extract parameters from low probability of intercept radar signals, are currently moving away from Fourier-based analysis and moving towards classical time-frequency analysis techniques, such as the WVD and the RSPWVD, for the purpose of analyzing low probability of intercept radar signals. Based on the research performed for this paper (the novel direct comparison of the WVD versus the RSPWVD for the signal analysis of low probability of intercept frequency hopping radar signals) it was shown that the RSPWVD by and large outperformed the WVD for analyzing these low probability of intercept radar signals - for reasons brought out in the discussion section above. More accurate characterization metrics may well equate to saved equipment and lives.

Future plans include analysis of an additional low probability of intercept radar waveform 8-component frequency Hopper, again using the WVD and the RSPWVD as time-frequency analysis techniques.

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Matching Device for AD-25/CW-3512 Broadband Antenna System Adaptive to Changing Load Impedance

By Dubovik Ilya Andreevich, Boykachev P. V. & Isaev V. O.

Abstract- The mathematical model of an adaptive matching device is presented, taking into account the deviation of the load impedance and the parameters of the matching circuit, based on this mathematical model, an adaptive matching device was synthesized for the AD-25/CW-3512 broadband antenna, which made it possible to reduce the loss of the power transmission coefficient level from the input (output) of the path to the AC and increase the potential range of the radio link from 2 to 15% in the framework of the presented experimental studies.

Keywords: coordination, method, sensitivity, load, broadband, mathematical model, adaptation.

GJRE-F Classification: DDC Code: 621.3845 LCC Code: TK6570.M6

MATCHINGDEVICEFORAD25CW3512BROADBANDANTENNASYSTEMADAPTIVETOCHANGINGLOADIMPEDANCE

Matching Device for AD-25/CW-3512 Broadband Antenna System Adaptive to Changing Load Impedance

СОГЛАСУЮЩЕЕ УСТРОЙСТВО ДЛЯ ШИРОКОПОЛОСНОЙ АНТЕННОЙ СИСТЕМЫ AD-25/CW-3512 АДАПТИВНОЕ К ИЗМЕНЯЮЩЕМУСЯ ИМПЕДАНСУ НАГРУЗКИ

Dubovik Ilya Andreevich [α], Boykachev P. V. [σ] & Isaev V. O. [ρ]

Абстрактный- **Представлена математическая модель адаптивного согласующего устройства, учитывающая отклонение импеданса нагрузки и параметров согласующей цепи, на основе данной математической модели было синтезировано адаптивное согласующее устройство для широкополосной антенны AD-25/CW-3512, что позволило уменьшить потери уровня коэффициента передачи по мощности от входного (выходного) тракта к АУ и увеличить потенциальную дальность радиолинии от 2 до 15% в рамках представленных экспериментальных исследований.**

Abstract- The mathematical model of an adaptive matching device is presented, taking into account the deviation of the load impedance and the parameters of the matching circuit, based on this mathematical model, an adaptive matching device was synthesized for the AD-25/CW-3512 broadband antenna, which made it possible to reduce the loss of the power transmission coefficient level from the input (output) of the path to the AC and increase the potential range of the radio link from 2 to 15% in the framework of the presented experimental studies.

Keywords: *coordination, method, sensitivity, load, broadband, mathematical model, adaptation.*

I. Введение

Проектирование высокочастотных приемо-передающих трактов с оптимальными частотными характеристиками, несомненно, является одной из важнейших радиотехнических задач, значимость которой возрастает в связи с освоением новых диапазонов частот и использованием в современных системах радиолокации, радионавигации, телевидения и мобильной связи сигналов со сложной структурой. В системах радиосвязи, обладающих исключительно большим значением в организации устойчивого управления войсками в условиях современного боя, для обеспечения связи личного состава воинских подразделений наблюдения, разведки, сил специальных операций и сухопутных войск, а также должностных лиц тактического звена управления, используются радиостанции VHF/UHF диапазонов, позволяющие функционировать в широком спектре частот (30–3000 МГц) в различных условиях эксплуатации [1, с. 5–8]. В тоже время следует заметить, что изменение условий эксплуатации приводит к изменению импеданса антенного устройства (АУ) и соответственно к изменению уровня передачи мощности между приемо-передающими модулями (ППМ) и антенной [2]. Это уменьшает потенциальные возможности радиостанций, в том числе потенциально достижимую дальность радиолинии [3]. Таким образом, актуальной является задача разработки устройств, позволяющих решить задачу обеспечения оптимальной работы радиотехнических систем (РТС) связи в различных условиях их эксплуатации.

a) Постановка задачи

В предыдущих публикациях на основании разработанной методики синтеза согласующих устройств (СУ) с учетом отклонения импеданса нагрузки была синтезирована цепь согласования для АУ AD-44/CW-TA-30-512, обеспечивающая уровень передачи мощности не менее 0,9 в различных

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условиях эксплуатации[3]. Однако использование представленного подхода для синтеза подобного рода цепей применительно к АУ AD-25/CW-3512 не представляется возможным. Дело в том, что реальная составляющая импеданса АУ AD-25/CW-3512 изменяется в диапазоне от 10 до 160 Ом[2]. В таких случаях положительный эффект функционирования может быть гарантирован только при наличии в системе адаптации [3]. Таким образом, целесообразно разработать СУ для АУ AD-25/CW-3512 адаптивное к изменению импеданса нагрузки и обеспечивающее требуемый уровень передачи мощности в различных условиях эксплуатации, в рабочем диапазоне частот.

b) Результаты экспериментального исследования по влиянию изменений условий эксплуатации на импеданс антенного устройства AD-25/CW-3512

В работе [2] были проведены экспериментальные исследования, показывающие вариации импеданса АУ в различных условиях эксплуатации носимых радиостанций (в помещении, в лесном массиве, в непосредственной близости с техникой, а также в безэховой камере). Результаты экспериментального исследования представлены на рисунке 1 в виде зависимостей реальной и мнимой составляющих импеданса нагрузки от частоты (полосы частот выбраны в соответствии с диапазонами работы радиостанции Р-181[4]) для различных условий эксплуатации.

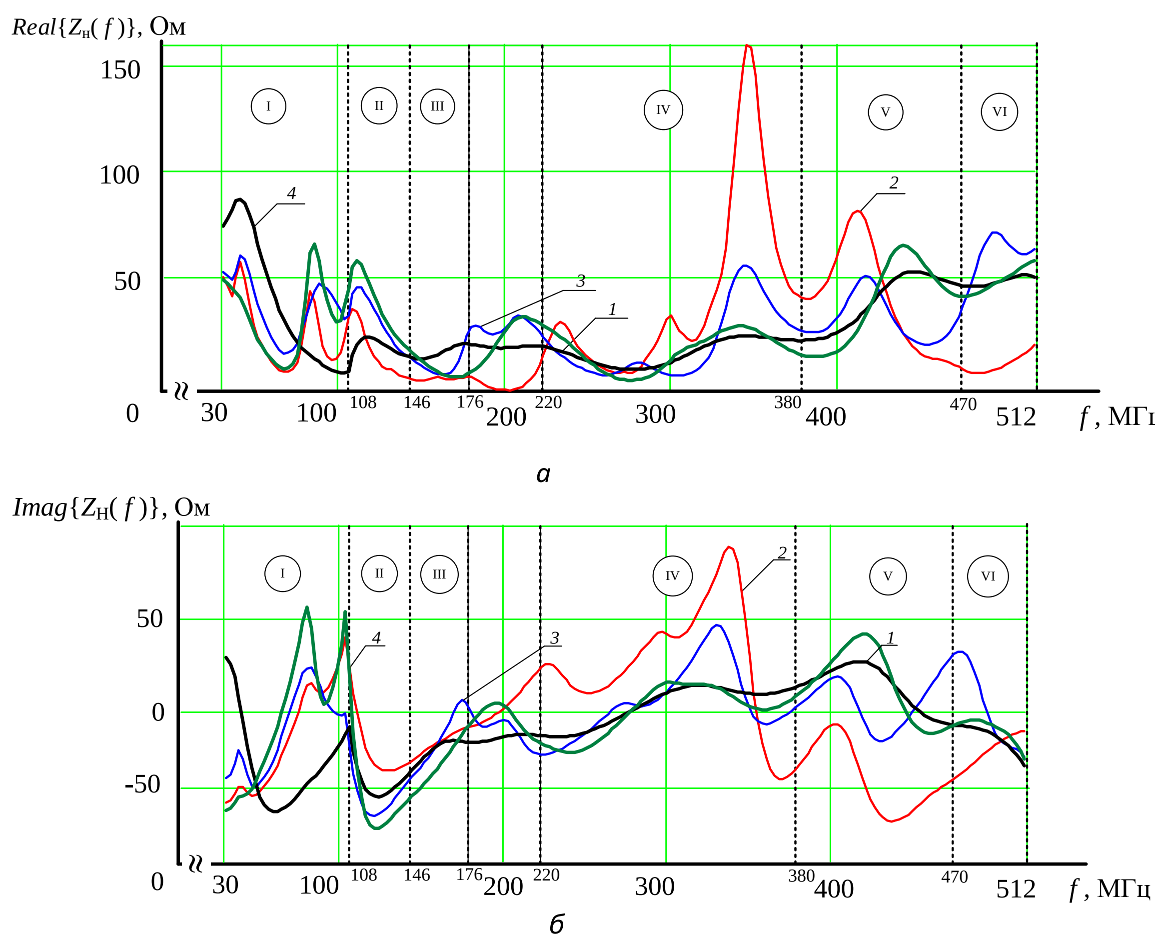

Рисунок 1: Зависимость изменения активной (*а*) и реактивной (*б*) частей импеданса антенны AD-25/CW-3512 в рабочей полосе частот:

1 – в экранизированной безэховой камере; 2 – в помещении;

3 – в лесном массиве; 4 – в непосредственной близости с техникой

Анализируя полученные результатов можно сделать определенные выводы:

– изменение условий эксплуатации приводит к изменению импеданса АУ относительно эталонного значения (в безэховой камере). Значительное изменение активной и реактивной составляющих импеданса АУ AD-25/CW-3512 наблюдается в помещении;

– существенное изменение импеданса приводи к изменению функции коэффициента передачи по мощности (КПМ), особенно это наблюдается в 2-6 диапазонах работы радиостанции(рисунок 2), несмотря на то, что АУ согласованно на линию с сопротивлением в 50 Ом[5].

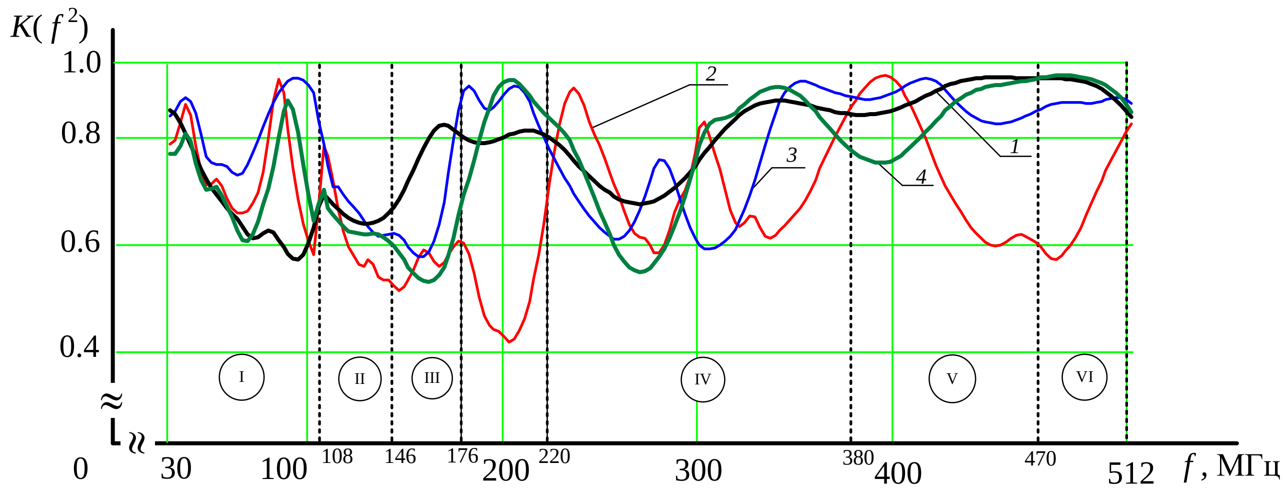

Рисунок 2: Зависимость коэффициента передачи по мощности антенны AD-25/CW-3512: 1 – в экранизированной безэховой камере; 2 – в помещении; 3 – в лесном массиве; 4 – в непосредственной близости с техникой

Кроме импеданса нагрузки и уровня КПМ в экспериментальном исследовании было рассмотрено влияние условий эксплуатации на дальность радиосвязи, потенциальные возможности которой можно оценить с помощью дальности радиолинии [6, с. 215]. В связи с тем, что работа посвящена уменьшению потерь передаваемой энергии полезного сигнала, расчет дальности радиолинии осуществлялся при условии, что все параметры радиостанции остаются неизменными, за исключением мощности передачи полезного сигнала от ППМ к АУ. Исходя из [2], изменение передачи мощности (рисунок 2) приводит к уменьшению дальности радиолинии на 15,8-22,2%, что может привести к потере связи между подразделениями. Таким образом, полученные результаты подтверждают актуальность поставленной задачи.

c) *Математическая модель согласующего устройства адаптивного к изменению импеданса нагрузки*

Под адаптивным устройством согласования комплексной нагрузки с радиотехническим устройством понимают систему с отрицательной обратной связью (рисунок 3), анализирующую качество согласования и подстраивающую свои элементы в сторону улучшения согласования [4].

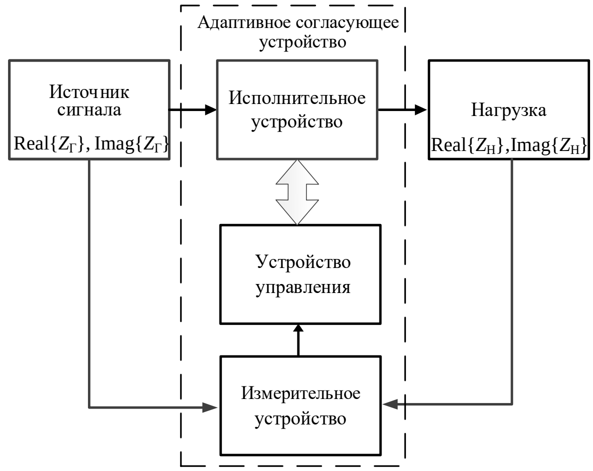

Рисунок 3: Структурная схема адаптивного согласующего устройства

Работа представленной схемы (рисунок 3) осуществляется следующим образом. Появление нежелательного отклонения (уровня КПМ, коэффициента стоячей волны (КСВ) и т. д.) обнаруживается и его значение измеряется. После чего приводятся в действие органы (перестраиваемые элементы адаптивного широкополосного согласующего устройства (ШСУ)), устраняющие отклонения путем соответствующего изменения значения управляемой величины. Следует отметить, что использование принципа обратной связи, при построении динамической системы, характеризуется простотой измерения отклонения исследуемой характеристики. При этом наибольший недостаток обратной связи (срабатывание после появления отклонения) устраняется путем многоразового измерения исследуемой характеристики.

В общем случае адаптивное ШСУ можно разбить на три составляющие (рисунок 3):

– измерительное устройство, предназначенное для измерения входных (выходных) параметров нагрузки (импедансные характеристики);

– управляющее устройство, преобразующее по определенному алгоритму информацию с измерительного устройства и формирующее команды исполнительному устройству;

– исполнительное устройство, предназначенное для изменения величин элементов согласующей цепи по команде управляющего устройства.

Из [5, с 138] следует, что для синтеза адаптивной системы необходимо выбрать, на основании заданных технических требований к качеству работы системы, критерии оптимальности.Так как основное предназначение системы является обеспечение требуемого уровня передачи мощности при наличии изменяющегося импеданса нагрузки, то необходимо определить оптимальное значение параметров широкополосного согласующего устройства (ШСУ), при котором суммарная среднеквадратичная ошибка уровня КПМ по отношению к требуемому значению будет минимальна [5 с. 136], т. е.:

$$\int_{f_н}^{f_в} \left[K(f)_{треб} - K(f, Z_н, Z_{сц}) \right]^2 d f \to \min, \tag{1}$$

где $K(f)_{треб}$ – требуемый уровень передачи мощности в нагрузку;

$K(f, Z_н, Z_{сц}) = 1 - \left| S_{in}(f, Z_н, Z_{сц}) \right|^2$ – функция КПМ;

$S_{in}(f, Z_н, Z_{сц}) = \dfrac{Z_н(f) - Z_{сц}(-f)}{Z_н(f) + Z_{сц}(f)}$ – функция коэффициента отражения;

$f_{н}$, $f_{в}$ – верхняя и нижняя частота рабочего диапазона;

$Z_{н}(f)$ – комплексное сопротивление нагрузки;

$Z_{сц}(f)$– комплексное сопротивление согласующего устройства.

В [3] было установлено, что для обеспечения требуемого уровня передачи мощности при наличии изменяющегося импеданса нагрузки необходимо, чтобы синтезируемое СУ обладало свойством минимальной чувствительности [9, с. 51] функции коэффициента отражения к изменению параметров нагрузки. В виду того, что импеданс нагрузки будет рассматриваться как измеренное значение реальной ($\mathrm{Real}\left[Z_{Н}(f)\right]$) и мнимой части ($\mathrm{Imag}\left[Z_{Н}(f)\right]$) комплексного сопротивления на дискретном ряде частот, то выполнение поставленной задачи (расчета функции чувствительности) предлагается выполнять с помощью статистического метода анализа [9]. Этот метод применим к случайным величинам, в частности к отклонениям параметров нагрузки от номинального значения внутри поля допусков [10, с. 156]. Знание функции чувствительности, характеризующей степень влияния элементов на характеристики схемы, позволяет с определенной вероятностью [10, с. 157] найти среднеквадратичное отклонение (СКО) модуля функции коэффициента отражения, рассчитанного по формуле:

$$\sigma_{|s_{in}|}{}^{2} = \left|S_{Z_{Н}}^{|S_{in}|}\right|^{2} \sigma_{Z_{Н}}{}^{2} \left(\frac{\Delta Z_{Н}}{Z_{Н}}\right)^{2}, \tag{2}$$

где $\sigma_{Z_{Н}}{}^{2}\left(\frac{\Delta Z_{Н}}{Z_{Н}}\right)$– СКО импеданса нагрузки;

$\Delta Z_{Н}$ –допустимое отклонение импеданса нагрузки;

$S_{Z_{Н}}^{|S_{in}|} = \mathrm{Re}\left[\frac{2\mathrm{Re}\left(Z_{сц}(f)\right)Z_{н}(f)}{\left(Z_{н}(f)+Z_{сц}(f)\right)\left(Z_{н}(f)-Z_{сц}(f)\right)}\right]$ – чувствительности модуля функции коэффициента отражения к изменению параметров нагрузки[3].

Однако кроме изменения импеданса нагрузки необходимо еще и рассматривать влияние отклонения параметров ШСУ от заданного значения, так как для проектирования СУ применяются схемные элементы, номиналы которых в процессе эксплуатации могут изменяться [10, с. 146-147].

В качестве примера на рисунке 4 представлены зависимости уровня КПМ от частоты, с учетом отклонения элементов СЦ [19] (ряд номиналов E24 (±5 %) (рисунок 4,*а*) и E12 (±10%) (рисунок 4,*б*)), функционирующей от 47 до 158 МГц. В представленных зависимостях наблюдается изменениеуровня КПМ (рисунок 4*2*, *3*) относительно исходной зависимости (рисунок 4,*1*), при условии, что параметры нагрузки остаются фиксированными.

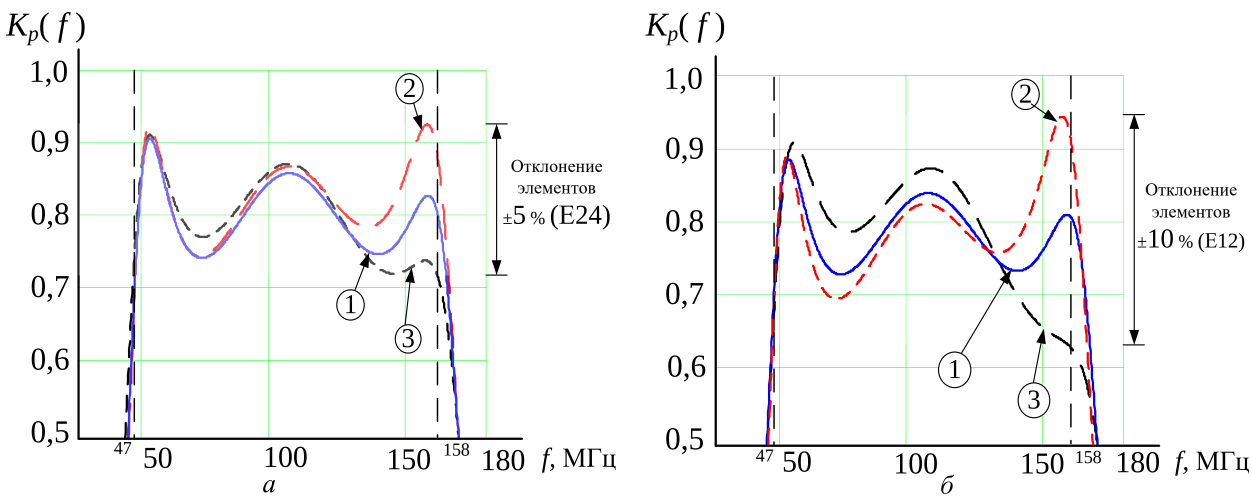

Рисунок 4: Зависимость КПМ от частоты с учетом отклонения элементов СЦ [19]

Таким образом, полагая, что отклонение импеданса нагрузки и элементов согласующего устройства, в силу «Центральной предельной теоремы» [11], подчиняется нормальному закону распределения, то дисперсию относительного изменения модуля функции коэффициента отражения можно определить с помощью выражения:

$$\sigma_{\text{К}}(f)^2 = \left|S_{Z_\text{Н}}^{|S_{in}|}(f)\right|^2 \sigma_{Z_\text{Н}}^2 + \sum_{i=0}^{N_C}\left|S_{C_i}^{|S_{in}|}(f)\right|^2 \sigma_{C_i}{}^2 + + \sum_{i=0}^{N_L}\left|S_{L_i}^{|S_{in}|}(f)\right|^2 \sigma_{L_i}{}^2, \qquad (3)$$

где $\sigma_{Z_\text{Н}}^2 = \left(\sigma^2\left\{\text{Real}\left[Z_{\text{изм}}\right]\right\} + \sigma^2\left[\text{Real}\left\{Z_\text{Н}\left(f_i\right)\right\}\right]\right) + j\left(\sigma^2\left[\text{Imag}\left\{Z_{\text{изм}}\right\}\right] + \sigma^2\left[\text{Imag}\left\{Z_\text{Н}\left(f_i\right)\right\}\right]\right)$ –дисперсия реальной и мнимой составляющих функции сопротивления нагрузки с учетом погрешности измерителя ($\sigma^2\left\{\text{Real}\left[Z_{\text{изм}}\right]\right\}, \sigma^2\left\{\text{Imag}\left[Z_{\text{изм}}\right]\right\}$);

$$S_{L_i}^{|S_{in}|}(f) = \text{Re}\left\{\frac{-4\left[2Z_\text{н}(f) + \frac{1}{2}\text{Im}\left(Z_\text{сц}(f)\right)\right]}{\left[Z_\text{н}(f) + Z_\text{сц}(f)\right]^2}\frac{\partial\,\text{Re}\left[Z_\text{сц}(f)\right]}{\partial L_i}\right\}$$

–чувствительность модуля функции коэффициента отражения к изменению индуктивности согласующей цепи;

$$S_{C_i}^{|S_{in}|}(f) = \text{Re}\left\{\frac{-4\left[2Z_\text{н}(f) + \frac{1}{2}\text{Im}\left(Z_\text{сц}(f)\right)\right]}{\left[Z_\text{н}(f) + Z_\text{сц}(f)\right]^2}\frac{\partial\,\text{Re}\left[Z_\text{сц}(f)\right]}{\partial C_i}\right\}$$

– чувствительность модуля функции коэффициента отражения к изменению емкости согласующей цепи;

σ_C, σ_L – СКОноминалов элементов цепи (E24{ ± 5%}, E48 { ± 2%} и т.д.).

Для того, чтобы обеспечить наименьшее влияние изменения импеданса нагрузки и элементов цепи необходимо, чтобы выражение (3) было минимизировано, ограничиваясь при этом номиналами элементов цепи, находящихся в магазине элементов исполнительного устройства ($C_{\min}$….$C_{\max}$, $L_{\min}$…..$L_{\max}$). Таким образом, критерий оптимальности, может быть представлен следующим выражением:

$$\begin{cases} \left\{ K(f)_{\text{треб}} - \left[K\left(f^2\right) - \sigma_K(f) \right] \right\}^2 \leq \varepsilon \quad f_{\text{н}} \leq f \leq f_{\text{в}} \\ \sigma_K(f)^2 \to \min \; f_{\text{н}} \leq f \leq f_{\text{в}}; \\ C_{\min} \leq C_i \leq C_{\max}; \\ L_{\min} \leq L_i \leq L_{\max}, \end{cases} \quad (4)$$

где в качестве задаваемых параметров используется допустимое отклонение уровня КПМ ε от требуемого значения.

Использование выражения (4) в качестве целевой функции позволяет уменьшить степень влияния изменения импеданса нагрузки и номиналов элементов СУ, в результате чего повышается эффективность работы радиотехнических устройств в различных условиях эксплуатации. В дополнении к этому учет отклонения импеданса нагрузки позволит находить параметры согласующего устройства, обеспечивающие меньшее количество переключений (коммутаций) магазина элементов, что увеличит время наработки на отказ и надежности радиотехнического устройства. Структура адаптивного согласующего устройства (исполнительного устройства) может быть найдена с помощью методики синтеза представленной в [3].

Таким образом, на основании полученных результатов и результатов представленных в [2,3,12-14] была разработана математическая модель адаптивного согласующего устройства, алгоритм расчета параметров которой представлен на рисунке 5.

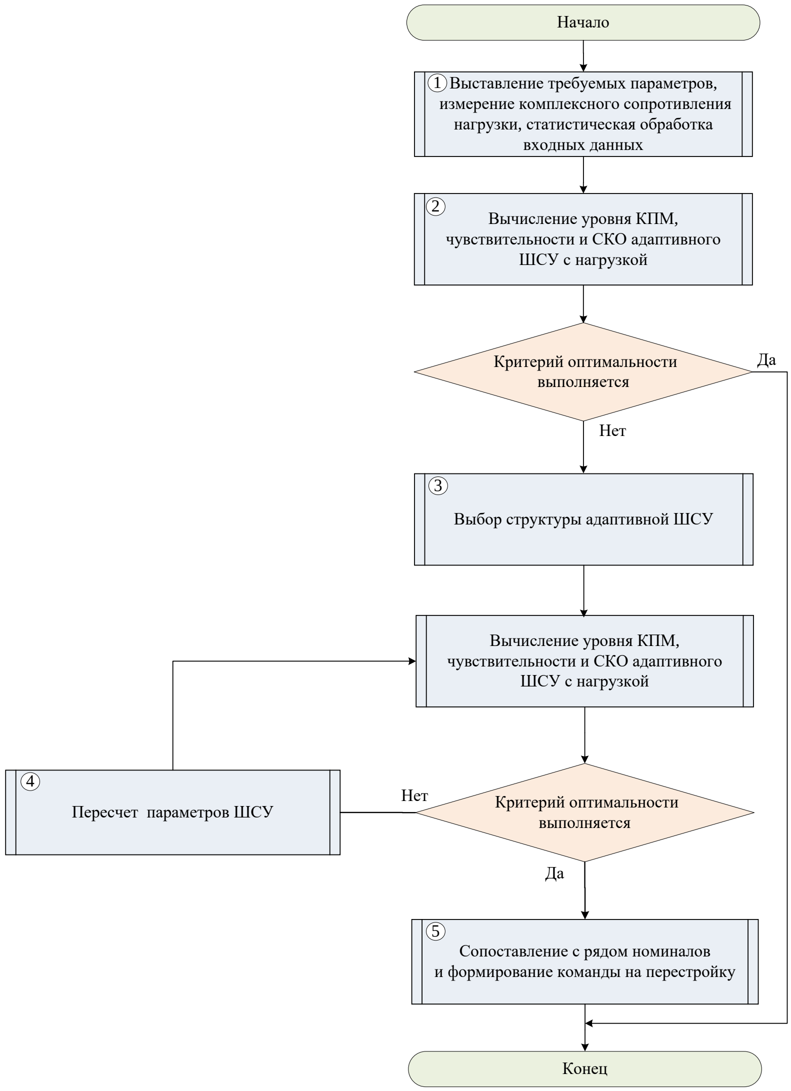

Рисунок 5: Обобщенный алгоритм расчета параметров математической модели адаптивного согласующего устройства

Суть алгоритма заключается в нахождении ШСУ, которое обеспечивает выполнение критерия оптимальности (выражение 4), ограничиваясь при этом допустимым магазином элементов. Достоинство математической модели заключается в предварительном расчете параметров ШСУ, значение которых обеспечивает требуемый уровень передачи мощности в различных условиях эксплуатации радиотехнических устройствине осуществляет поиск значения параметров методом перебора. Еще одно немаловажное достоинство математической модели – способность системы согласовывать нагрузку с радиотехническим устройством не во всей полосе частот, а только в той, где станция работает в текущий момент времени. Это позволяет уменьшить полосу согласования и применять ШСУ более эффективно.

Следует отметить, что на практике реактивные элементы неидеальны и обладают резистивным сопротивлением (сопротивлением потерь *r*). Для его учета используют такой параметр, как добротность *Q* определяющейся с помощью:

$$Q_{Li} = 2\pi f_i L / r \; ; \qquad (5)$$

Global Journal of Researches in Engineering (F) Volume XXII Issue III Version I Year 2022

$$Q_{Ci} = 2\pi f_i Cr\,. \qquad (6)$$

В доступной технической документации содержится информация о добротностях номиналов индуктивностей и емкостей на некоторой частоте измерения. Эта информация оказывается полезной не только на этапе моделирования схем, но и на этапе их расчета. Известные величины добротностей, используемых элементов, позволяют рассчитывать параметры СЦ по заданным критериям оптимальности с учетом тепловых потерь и тем самым максимально приблизить характеристики рассчитываемых схем к характеристикам их экспериментальных аналогов.

На основании разработанной математической модели был разработан специализированный экспериментальный комплекс расчета и контроля функционирования согласующих устройств врадиотехнических системах (РТС) (рисунок 6), состоящий из измерительного устройства, устройства управления (программно-имитационная модель) и средства индикации.

Рисунок 6: Специализированный экспериментальный комплекс расчета и контроля функционирования согласующих устройств в РТС

Экспериментальный комплекс позволяет контролировать изменение уровня передачи мощности между трактами РТС вызванных разбросом значений номиналов элементов цепи и вариаций импеданса нагрузки, а также рассчитывать параметры согласующего устройства по заданному критерию, что обеспечивает устойчивую работу РТС в условиях изменяющегося импеданса нагрузки.

d) Синтез СУ для АУ AD-25/CW-3512 адаптивного к изменяющемуся импедансу нагрузки

На основании поставленной задачи с помощью предложенной математической модели было разработано адаптивное СУ для АУ AD-25/CW-3512. Электрическая схема исполнительного устройства адаптивного ШСУ, состоящая из шести реактивных элементов, представлена на рисунке 7.

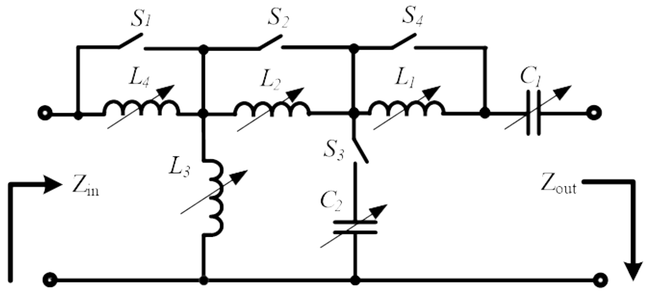

Рисунок 7: Электрическая схема исполнительного устройства адаптивного ШСУ

Функция сопротивления, описывающая данное адаптивное ШСУ, выглядит следующим образом:

$$Z_{\text{сц}}(s) = \frac{a_0 + a_1 s + a_2 s^2 + a_3 s^3 + a_4 s^4 + a_5 s^5}{b_0 + b_1 s + b_2 s^2 + b_3 s^3 + b_4 s^4 + b_5 s^5}. \quad (7)$$

Коэффициенты функции числителя (a_i) и знаменателя (b_i) $Z_{\text{сц}}(s)$ описываются значениями элементов цепи (L,C,R):

$$\begin{cases} a_0 = R; \\ a_1 = L_3 + L_4; \\ a_2 = C_1 L_1 R + C_1 L_2 R + C_2 L_3 R; \\ a_3 = C_1(L_1L_4 + L_1L_3 + L_2L_3 + L_2L_4 + L_3L_4) + C_2(L_2L_3 + L_2L_4 + L_3L_4); \\ a_4 = C_1C_2L_1R(L_3 + L_2); \\ a_5 = C_1C_2L_1(L_3L_4 + L_2L_4 + L_2L_3). \end{cases} \quad (8)$$

$$\begin{cases} b_0 = 0; \\ b_1 = C_1R; \\ b_2 = C_1(L_3 + L_4); \\ b_3 = C_1C_2R(L_2 + L_3); \\ b_4 = C_1C_2(L_3L_4 + L_2L_4 + L_2L_3); \\ b_5 = 0. \end{cases} \quad (9)$$

Параметры аналитической математической модели в виде параметров исполнительного устройства,значения которых приведены под ряд номиналов Е24, для рабочих диапазонов частот радиостанции Р-181 представлены в таблице 1.

Таблица 1: Параметры исполнительного устройства адаптивного ШСУ

Элементы	Диапазоны частот									
	I (30-108 МГц)	II (108-146 МГц)	III (146-174 МГц)	IV (220-380 МГц)			V (380-470 МГц)		VI (470-512 МГц)	
C_1,пФ	200	200	62	26	29	12	95	9.5	15.6	6
L_1, нГн	18,6	66	4	–	–	–	–	–	–	3.5
L_2, нГн	26,21	–	–	–	–	11	–	7,5	–	–

Global Journal of Researches in Engineering (F) Volume XXII Issue III Version I Year 2022
20

L_3, нГн	300	35	52	21	33	24	121	130	29	65
L_4, нГн	11,3	–	3	–	–	2	–	2,5	7	28
C_2,пФ	32	10	-	8	–	9	–	–	–	–

« – »–элемент равен нулю и исключается из согласующей цепи

Следует отметить, что принципиальная схема, представленная на рисунке 6, может быть выполнена на реактивных элементах, реле или pin–диодах в SMD исполнении. Устройство управления может быть реализовано на ПЛИС или микроконтроллере, а измерительное устройство -в виде радиочастотного измерительного моста (микропроцессора). Так, в качестве примера на рисунке 6 представлена 3D модель возможного варианта исполнения разработанного адаптивного согласующего устройства размерами (52,5×42,5×2 мм^3), реализованная в среде моделирования радиотехнических устройств CST Studio [15]. Где в качестве реактивных элементов используются SMD элементы 0805 серии, в качестве измерительного устройстваи устройства управления-микропроцессор (1) в корпусе QFP, а в качестве коммутирующих устройств-аналоговые мультиплексоры (2) в корпусе PDIP.

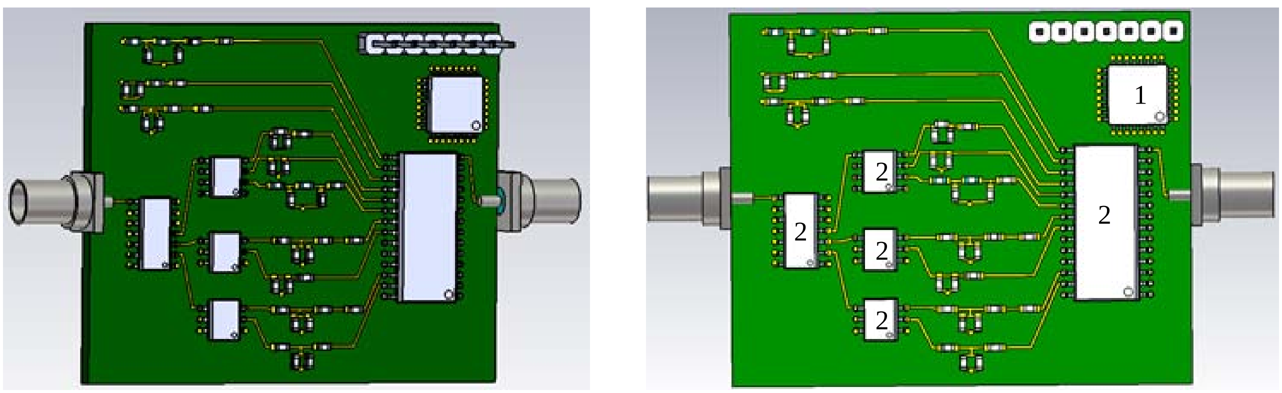

Рисунок 8: Пример 3D модели разработанного адаптивного согласующего устройства

Моделирование синтезированного согласующего устройства проводилось в AWR Microwave Studio 14 [16]. Результаты моделирования представлены на рисунке 9 в виде зависимости КПМ от частоты для различных условий обстановки. Прерывистыми линиями показаны КПМ АУ без синтезированного адаптивного ШСУ (2), а сплошными линиями с синтезированным адаптивным ШСУ (1).

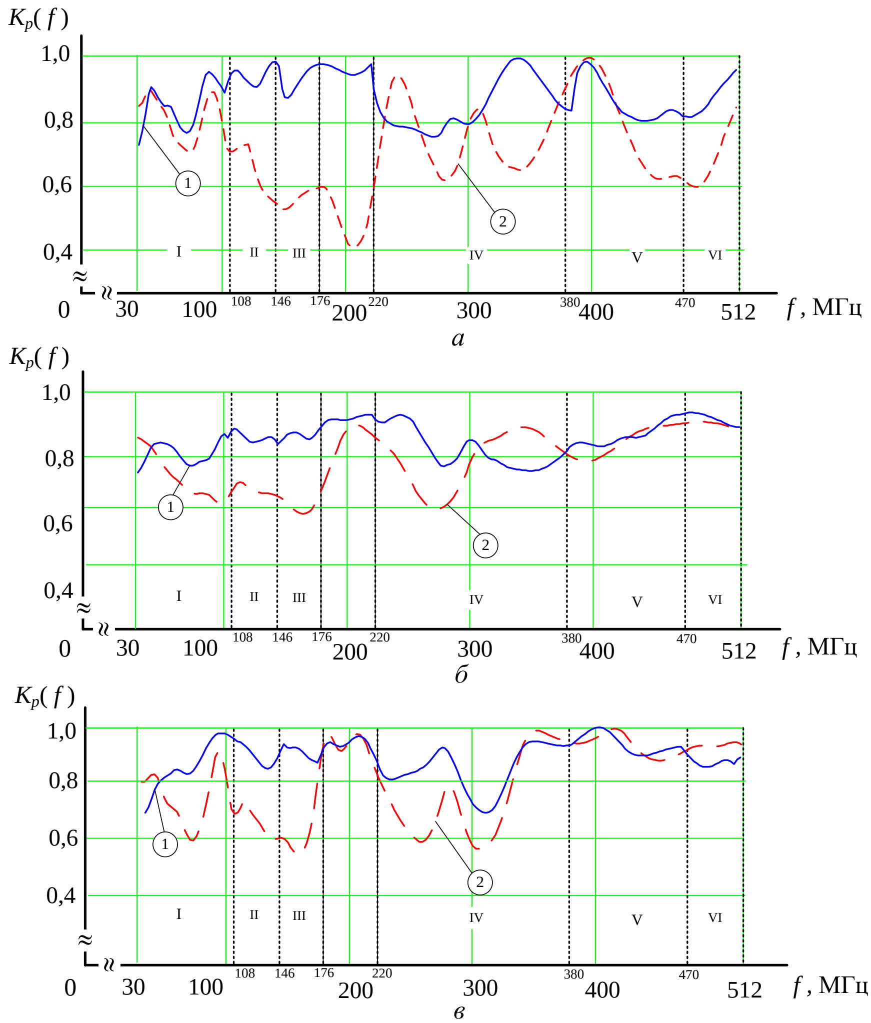

Рисунок 9: Зависимость КПМ от частоты АУ AD-25/CW-3512:
а- в помещении; *б*- в непосредственной близости с техникой; *в*- в лесном массиве

Исходя из полученных результатов можно сделать вывод о том, что синтезированное адаптивное ШСУ обеспечивает более высокий уровень передачи мощности при работе радиостанции в различных условиях обстановки. Так, при расположении АУ в помещении (наихудший случай) потери уровня КПМ (исходя из [17, с. 36-38]) составляют 39,7% (в III диапазоне) от максимального значения (19,7% в дальности радиолинии [6, с. 215]), а при использовании адаптивной ШСУ-8,6% (4,4 %в дальности радиолинии). В таблице 2 представлены усредненные значения потерь в уровне передачи мощности ($\Delta K(f^2)$) и в дальности радиолинии (ΔR_{max}) для различных диапазонов частот.

Таблица 2: Потери уровня передачи мощности идальности радиолинии

Условия эксплуатации	Диапазоны частот											
	I (30-108 МГц)		II (108-146 МГц)		III (146-174 МГц)		IV (220-380 МГц)		V (380-470 МГц)		VI (470-512 МГц)	
	$\Delta K(f^2)$	ΔR_{max}	$\Delta K(f^2)$	ΔR_{max}	$\Delta K(f^2)$	ΔR_{max}	$\Delta K(f^2)$	ΔR_{max}	$\Delta K(f^2)$	ΔR_{max}	$\Delta K(f^2)$	ΔR_{max}
Без	21,3	11,3	31,4%	17,2	36,3	20.2	19%	10%	11,3	5,8%	12,2	6,3%

адаптивн ого ШСУ	%	%		%	%	%			%		%	
С адаптивн ым ШСУ	16,4 %	8,6%	9,6%	4,9 %	9,8%	5%	13,2 %	6,8%	8,1%	4,1%	7,8%	4%

Таким образом, синтезированное адаптивное ШСУ обеспечивает уменьшение потерь уровня КПМ отвходного (выходного) тракта к АУ радиостанции Р-181 на 3 – 26 %, что позволяет увеличить усредненную потенциально достижимую дальность действия радиолинии [6, с. 215] для АУ от 2 % до 15%в рамках представленных экспериментальных исследований.

II. Заключение

Для выполнения поставленной задачи была разработана математическая модель адаптивного ШСУ, обеспечивающая увеличение уровня передачи мощности в различных условиях эксплуатации за счет уменьшения дисперсии модуля функции коэффициента отражения. На основе которой было синтезировано адаптивное ШСУ для АУ AD-25/CW-3512, что позволило увеличить потенциальную дальность радиолинииот 2 до 15% в рамках представленных экспериментальных исследований.

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Lighting Characterization of the General Bank Operation Center in Panama

By Ana Gabriela Araúz, Cathleen Lee, Diego Segundo & Jorge Perém
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Abstract- Illumination represents one of the main factors that affect energy consumption on a building, this consumption is even more on an office building. This study presents quantitative and qualitative data of the south façade of an open-plan office in Panama of a building that has a system to regulate internal light. To accomplish this, several measurements of illuminance in three different sceneries: evaluating daylight factor, measuring illuminance levels (lx) and luminance levels with users' perception. It was concluded that the building requires this system of light control to operate correctly, 75% of the participants describe their workplace as comfortable.

Keywords: post occupancy evaluation, daylight, daylight factor, open-plan office.

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LIGHTINGCHARACTERIZATIONOFTHEGENERALBANKOPERATIONCENTERINPANAMA

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Ana Gabriela Araúz [α], Cathleen Lee [σ], Diego Segundo [ρ] & Jorge Perém [Ѡ]

Abstract- Illumination represents one of the main factors that affect energy consumption on a building, this consumption is even more on an office building. This study presents quantitative and qualitative data of the south façade of an open-plan office in Panama of a building that has a system to regulate internal light. To accomplish this, several measurements of illuminance in three different sceneries: evaluating daylight factor, measuring illuminance levels (lx) and luminance levels with users' perception. It was concluded that the building requires this system of light control to operate correctly, 75% of the participants describe their workplace as comfortable.

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I. Introduction

In Panama there are no official standards that regulate illumination standards in building design and construction. Being lighting one of the principal factors of electricity consumption [1], it can suppose an issue in terms of energy efficiency. In tropical climates, artificial conditioning, and lighting are the highest factors. This last one depends on four principal aspects: building use, daylight availability, levels of illumination, and operation hours. [2].

Office buildings usually emit more heat than other building types because of the equipment and large groups of people in them [3], this means that the energy they require is higher. Appropriate lighting level is indispensable in a work area because it improves performance, helps to make fewer mistakes, decreases accidents, and therefore improves productivity. [4].

There are different classifications of office spaces: private offices, shared offices (two to five employees), and open offices (more than five employees) [5]. This last configuration is the one studied in this paper, under the criterion that it is the most critical scenario because it is the one with the most people under the same conditions.

It is essential to mention that natural light is a source that fluctuates in color, intensity, direction, and availability, making field studies hard to conduct and potentially challenging to translate between different types of climates [6]. The objective of this study is to collect quantitative and qualitative data from an open office in Panama and to know if the illuminance, a magnitude that expresses the luminous flux on the surface unit and whose unit in the international system is lux (lx), manages to satisfy the users need.

Fig. 1 Fotografía del Centro de Operaciones Banco General.

Fig. 2 Localización y orientación del caso de estudio, Centro de Operaciones Banco General, Ciudad Radial

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II. Methodology

a) Case Study

The case study for this research is the Bank Operations Center *(Centro de Operaciones de Banco General)* in Panama City, Panama (Fig. 1 and 2). It is an eight-story parallelepiped facing north with approximate dimensions of 85.00 m x 43.00 m. It has a control system for artificial lighting and blinds. The artificial lighting system for the most part works with Alera Lighting 28watt lights, *RI 85 (T5) Model CV-4-2T5-FCM18-ESD-MW* along with an electrical transformer (Lutron Ecosystems H-Series Dimming fluorescent ballast for T5 lights 28 watts) that regulates the intensity of the light depending on the global horizontal light (lx outside). Every light fixture is regulated by Quantum Vue software on each story.

The blinds are located around the entire perimeter of the building and operate electronically as well. Their model is *Tapparelle Reflex 4000* and the engine they operate with is Somfy Sonesse model: 50RS485. They usually work automatically taking constant data from the horizontal global light but can be adjusted manually using the Animeo software. The lighting levels were calibrated by a private vendor.

Three different scenarios are studied (Table 1): daylight factor, illuminance levels (lx), and illuminance levels together with the user's perception, this last one, through a post-occupancy evaluation (POE: Post-occupancy evaluation). In all cases, three EXTECH SD 4000 light meters are used in manual mode, each meter corresponding to one of the three axes A, B, and C (Fig. 3 and 5). Measurements were made from west to east at the height of the user's work plane (0.73 m) (Fig. 4).5.00 m x 43.00 m.

b) Daylight Factor

The Daylight Factor (DF) is the ratio of the internal illuminance to the external horizontal illuminance under a cloudy sky. This lighting tool is criticized for its lack of realism [8], it is ideally applied in simulations because the parameter to evaluate it is a completely cloudy sky. However, it is the most common tool currently in practice for calculating lighting levels [9]. On July 14 (Table 1), the lights in the study area were turned off and the blinds were opened to assess the lighting conditions of the workspace without the assistance of any resource outside the architecture of the building itself. Subsequently, the natural light factor was calculated for each case.

$$DF = \frac{horizontal\ global\ illumination}{interior\ lx} \times 100$$

c) Illuminance Measurement

The previous methodology was repeated, only the results were placed in the architectural plan in lx.

d) Post-Occupancy Evaluation

A visual evaluation survey [7] [8] was applied to the users of the third floor, south façade on July 26 under normal working conditions (Table 1). Not all users were available to participate due to the type of work they did, it is worth mentioning that more than half of the users in the study area did not participate in the survey. Simultaneously with the post-occupation evaluation, internal illuminance measurements were made, for this reason the duration of the measurements on this day is greater than ten minutes (Table 1).

The survey and the measurements were carried out at the same time to obtain a relationship between the existing illuminance levels on a regular day, with the light regulation system in automatic mode, and the perception of the users.

To determine if the illuminance levels are adequate, we refer to the lighting standards of the Illuminating Engineering Society (IES), American standards, and MS1525:2014, Malaysian standards. These two were chosen to have as a reference a more widely used standard worldwide, the IES, and another that would be applied in a climate like Panama's. (Table 2).

Table 1

Days and scenarios description during the evaluation

Date	Time start	Time finish	Horizontal global illumination	Lights	SOUTH blind clousure %	EAST blind clousure %	WEST blind clousure %	Survey
July 14	12:31	12:43	38.8 k lx	OFF	0%	100%	0%	NO
July 16	11:43	11:52	25.9 k lx	ON	89%	100%	74%	NO
July 26	10:47	11:32	22.8 k lx	ON	80%	100%	76%	YES

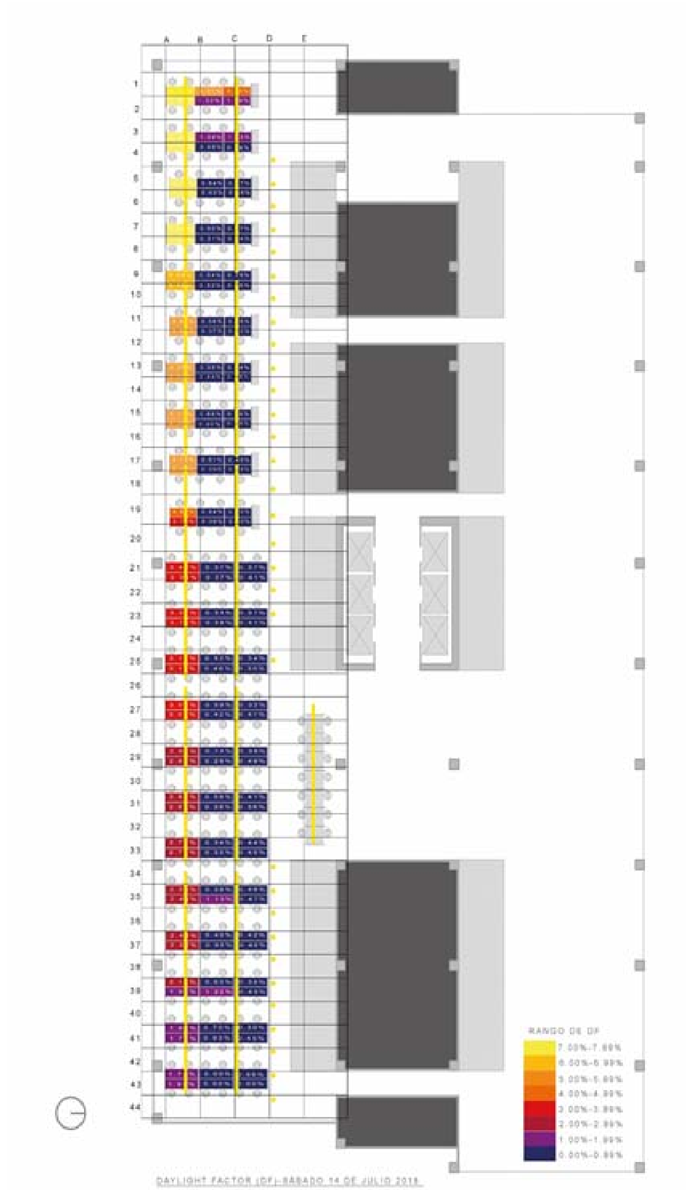

Fig. 3 Factor de luz natural en fachada sur, nivel 3

III. Results

a) *Daylight Factor*

The values of July 14 were quite high (Fig. 5). The workstations closest to the façade present a higher natural light factor than those closest to the core of the building.

As the measurements were made towards the east façade, the light levels were reduced in both cases because the shutters on the east façade were kept permanently closed (Table 1).

b) *Illuminance Level Measurement*

Under normal working conditions, that is, using automated support systems for interior light control, illuminance levels remained quite similar (Fig. 6). The approximate ranges in which the system-maintained illuminance was between 300 lx - 400 lx for the most part (Fig. 6). It means that within the MS1525:2014 standards, it is at an appropriate level. However, there are workspaces that marked in the range of 200 lx, below this standard and even much lower than that of the IES. (Table 2).

c) *Post-Occupancy Evaluation*

A total of 37 surveys were completed throughout the study area. 75% of the surveyed users describe their work space as comfortable in terms of lighting (Fig. 7). As for performing tasks on the computer, 51% feel satisfied and 30% choose the

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neutral option. Regarding paper tasks, 43% say they feel satisfied and 43% choose the neutral option. (Fig. 8)

Only 16% of the participants reported experiencing glare in their work area. Of them, 50% said that the glare is from sunlight on the computer screen and 33% said that it is from direct sunlight.

35% prefer equal dependence on electric light and natural light, followed by 30% who prefer predominant dependence on natural light with electric light support (Fig. 9).

IV. Discussion

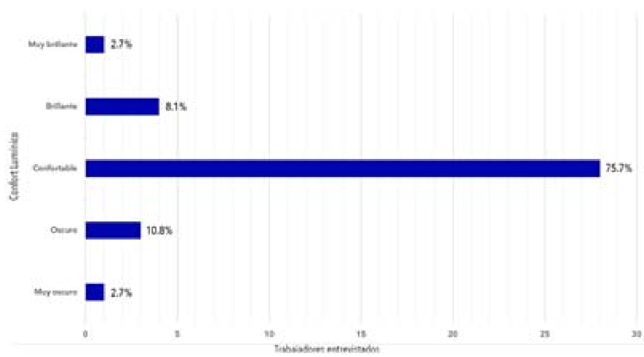

Fig. 7 Resultados de percepción de confort lumínico en puestos de trabajo.

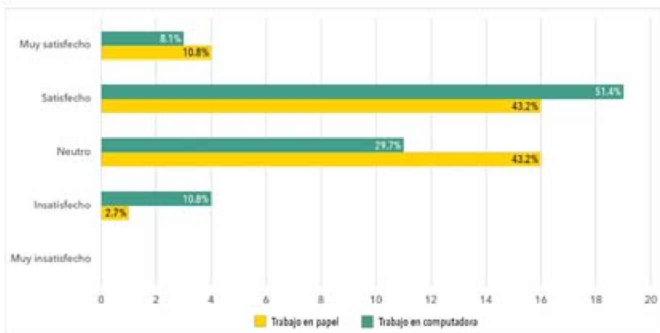

Fig. 8 Resultados de niveles de satisfacción para leer y escribir en computadora y en papel

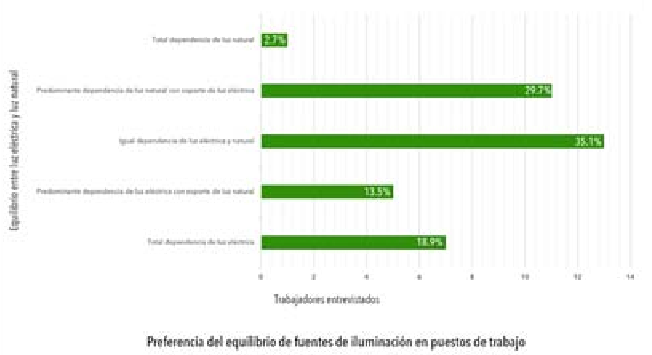

Fig. 9 Resultados de preferencia de fuentes de iluminación en puestos de trabajo

Table 2

Comparison between illuminance (lx) standards				
Standard	Office administration task	Deep plane office	Computer room	Drawing offices
IES	500	750	750	750
MS1525:2014	300-400	300-400	300-400	350

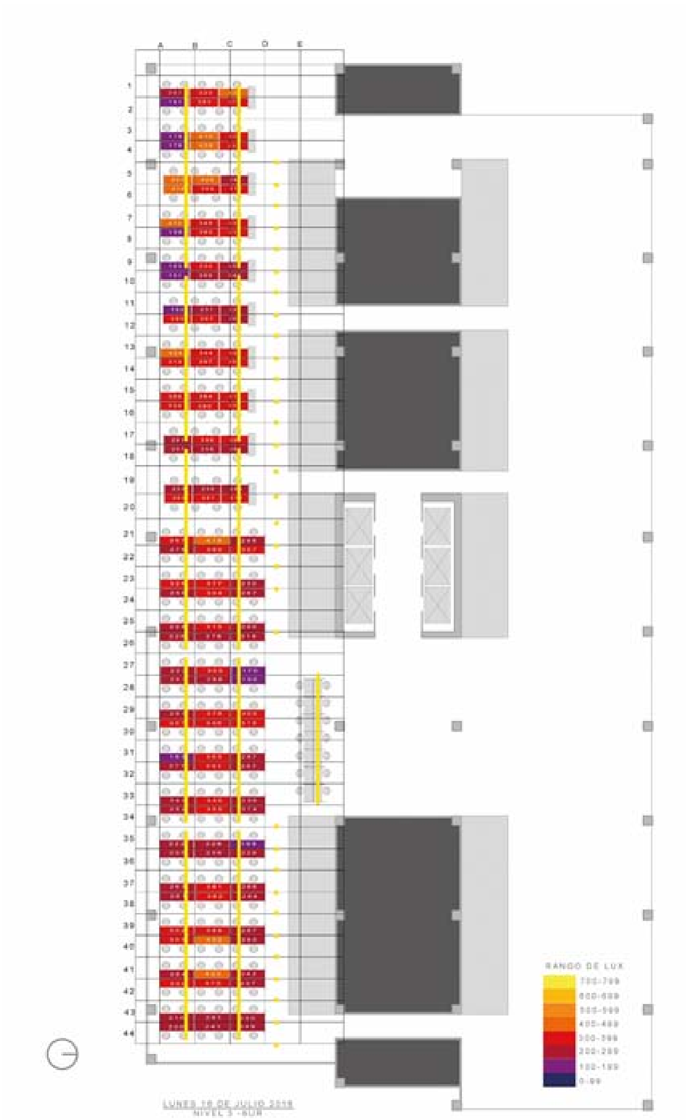

Fig. 6 Planta arquitectónica de nivel tres, niveles de iluminancia de 16 de julio

We consider that the Malaysian standards are more valid than those of the IES because in countries with tropical climates the incidence of the sun is greater, which means that the illuminance in areas with this climate is higher. When the shutters were opened on the 14th there were not so many people because it was a Saturday, however, the staff in charge of the automated system received complaints, from this fact we deduce a feeling of discomfort in the few people who were there. This may indicate that the building requires an additional system to function, this implies an extra cost for it, since the architectural design does not respond to changing weather conditions.

According to [9], if there is disagreement in 20% of users, changes must be made. The results gave 16% but considering that only 37 people of the jobs that exist in the entire floor (including the north facade) there is a great probability that the 4% missing for this parameter to be met may exist. Future long-term studies should be done on the entire floor to verify this. This 16% (yellow Fig.10) is located on the east side where there is a sill on the south façade (Fig.12). Our deduction is that the software is programmed for the window of (Fig. 11) and takes its full height to adjust its closing percentages. This height is different from that of the window (Fig. 12), so when the closing percentage is adjusted, on the side where the sill is, the adjustment will always be wrong.

Fig. 10 Planta arquitectónica de nivel tres, participantes de la evaluación post-ocupación y sus respuestas

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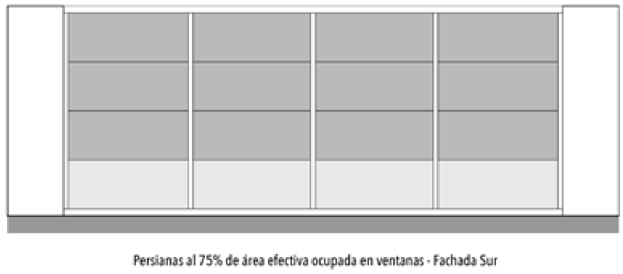

Fig. 11 Segmento de elevación de pared de fachada sur sin antepecho.

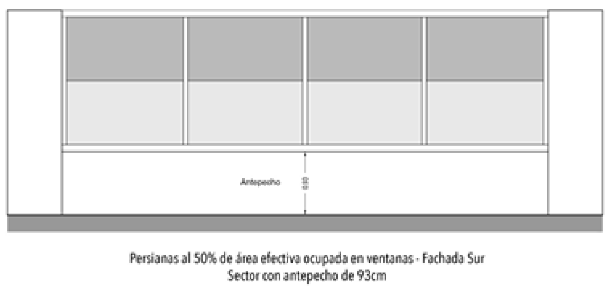

Fig. 12 Segmento de elevación de pared de fachada sur con antepecho.

V. Conclusions

Banco General's Operations Center with its natural light entry control system mostly satisfies the needs of users, since 75% of the participants in the post-occupancy evaluation described their workspace as comfortable. We could conclude that a building in the tropics with the same characteristics: north-south orientation, predominantly glass facades and for commercial use, requires automated systems outside of architecture to function properly.

This light control system inside the building is a good option to correct this type of design pathology; however, it does not adapt to the entire morphology of the building, as it has deficiencies when there is a sill on the façade.

A considerable percentage of the people answered neutral regarding such and such. This parameter can cause confusion, so it is recommended to use another level of evaluation in future post-occupancy evaluations. Likewise, case studies are recommended where people are more willing to stop their work to participate in a post-occupation evaluation.

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Authors must ensure the information provided during the submission of a paper is authentic. Please go through the following checklist before submitting:

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2. Authors must accept the privacy policy, terms, and conditions of Global Journals.
3. Ensure corresponding author's email address and postal address are accurate and reachable.
4. Manuscript to be submitted must include keywords, an abstract, a paper title, co-author(s') names and details (email address, name, phone number, and institution), figures and illustrations in vector format including appropriate captions, tables, including titles and footnotes, a conclusion, results, acknowledgments and references.
5. Authors should submit paper in a ZIP archive if any supplementary files are required along with the paper.
6. Proper permissions must be acquired for the use of any copyrighted material.
7. Manuscript submitted *must not have been submitted or published elsewhere* and all authors must be aware of the submission.

Declaration of Conflicts of Interest

It is required for authors to declare all financial, institutional, and personal relationships with other individuals and organizations that could influence (bias) their research.

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- Findings
- Writings
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- Graphs
- Illustrations
- Lectures

- Printed material
- Graphic representations
- Computer programs
- Electronic material
- Any other original work

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2. Drafting the paper and revising it critically regarding important academic content.
3. Final approval of the version of the paper to be published.

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The corresponding author should mention the name and complete details of all co-authors during submission and in manuscript. We support addition, rearrangement, manipulation, and deletions in authors list till the early view publication of the journal. We expect that corresponding author will notify all co-authors of submission. We follow COPE guidelines for changes in authorship.

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Unless specified in the notification, the Editorial Board's decision on publication of the paper is final and cannot be appealed before making the major change in the manuscript.

Acknowledgments

Contributors to the research other than authors credited should be mentioned in Acknowledgments. The source of funding for the research can be included. Suppliers of resources may be mentioned along with their addresses.

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Preparing your Manuscript

Authors can submit papers and articles in an acceptable file format: MS Word (doc, docx), LaTeX (.tex, .zip or .rar including all of your files), Adobe PDF (.pdf), rich text format (.rtf), simple text document (.txt), Open Document Text (.odt), and Apple Pages (.pages). Our professional layout editors will format the entire paper according to our official guidelines. This is one of the highlights of publishing with Global Journals—authors should not be concerned about the formatting of their paper. Global Journals accepts articles and manuscripts in every major language, be it Spanish, Chinese, Japanese, Portuguese, Russian, French, German, Dutch, Italian, Greek, or any other national language, but the title, subtitle, and abstract should be in English. This will facilitate indexing and the pre-peer review process.

The following is the official style and template developed for publication of a research paper. Authors are not required to follow this style during the submission of the paper. It is just for reference purposes.

Manuscript Style Instruction (Optional)

- Microsoft Word Document Setting Instructions.
- Font type of all text should be Swis721 Lt BT.
- Page size: 8.27" x 11'", left margin: 0.65, right margin: 0.65, bottom margin: 0.75.
- Paper title should be in one column of font size 24.
- Author name in font size of 11 in one column.
- Abstract: font size 9 with the word "Abstract" in bold italics.
- Main text: font size 10 with two justified columns.
- Two columns with equal column width of 3.38 and spacing of 0.2.
- First character must be three lines drop-capped.
- The paragraph before spacing of 1 pt and after of 0 pt.
- Line spacing of 1 pt.
- Large images must be in one column.
- The names of first main headings (Heading 1) must be in Roman font, capital letters, and font size of 10.
- The names of second main headings (Heading 2) must not include numbers and must be in italics with a font size of 10.

Structure and Format of Manuscript

The recommended size of an original research paper is under 15,000 words and review papers under 7,000 words. Research articles should be less than 10,000 words. Research papers are usually longer than review papers. Review papers are reports of significant research (typically less than 7,000 words, including tables, figures, and references)

A research paper must include:

a) A title which should be relevant to the theme of the paper.
b) A summary, known as an abstract (less than 150 words), containing the major results and conclusions.
c) Up to 10 keywords that precisely identify the paper's subject, purpose, and focus.
d) An introduction, giving fundamental background objectives.
e) Resources and techniques with sufficient complete experimental details (wherever possible by reference) to permit repetition, sources of information must be given, and numerical methods must be specified by reference.
f) Results which should be presented concisely by well-designed tables and figures.
g) Suitable statistical data should also be given.
h) All data must have been gathered with attention to numerical detail in the planning stage.

Design has been recognized to be essential to experiments for a considerable time, and the editor has decided that any paper that appears not to have adequate numerical treatments of the data will be returned unrefereed.

i) Discussion should cover implications and consequences and not just recapitulate the results; conclusions should also be summarized.
j) There should be brief acknowledgments.
k) There ought to be references in the conventional format. Global Journals recommends APA format.

Authors should carefully consider the preparation of papers to ensure that they communicate effectively. Papers are much more likely to be accepted if they are carefully designed and laid out, contain few or no errors, are summarizing, and follow instructions. They will also be published with much fewer delays than those that require much technical and editorial correction.

The Editorial Board reserves the right to make literary corrections and suggestions to improve brevity.

Format Structure

It is necessary that authors take care in submitting a manuscript that is written in simple language and adheres to published guidelines.

All manuscripts submitted to Global Journals should include:

Title

The title page must carry an informative title that reflects the content, a running title (less than 45 characters together with spaces), names of the authors and co-authors, and the place(s) where the work was carried out.

Author details

The full postal address of any related author(s) must be specified.

Abstract

The abstract is the foundation of the research paper. It should be clear and concise and must contain the objective of the paper and inferences drawn. It is advised to not include big mathematical equations or complicated jargon.

Many researchers searching for information online will use search engines such as Google, Yahoo or others. By optimizing your paper for search engines, you will amplify the chance of someone finding it. In turn, this will make it more likely to be viewed and cited in further works. Global Journals has compiled these guidelines to facilitate you to maximize the web-friendliness of the most public part of your paper.

Keywords

A major lynchpin of research work for the writing of research papers is the keyword search, which one will employ to find both library and internet resources. Up to eleven keywords or very brief phrases have to be given to help data retrieval, mining, and indexing.

One must be persistent and creative in using keywords. An effective keyword search requires a strategy: planning of a list of possible keywords and phrases to try.

Choice of the main keywords is the first tool of writing a research paper. Research paper writing is an art. Keyword search should be as strategic as possible.

One should start brainstorming lists of potential keywords before even beginning searching. Think about the most important concepts related to research work. Ask, "What words would a source have to include to be truly valuable in a research paper?" Then consider synonyms for the important words.

It may take the discovery of only one important paper to steer in the right keyword direction because, in most databases, the keywords under which a research paper is abstracted are listed with the paper.

Numerical Methods

Numerical methods used should be transparent and, where appropriate, supported by references.

Abbreviations

Authors must list all the abbreviations used in the paper at the end of the paper or in a separate table before using them.

Formulas and equations

Authors are advised to submit any mathematical equation using either MathJax, KaTeX, or LaTeX, or in a very high-quality image.

Tables, Figures, and Figure Legends

Tables: Tables should be cautiously designed, uncrowned, and include only essential data. Each must have an Arabic number, e.g., Table 4, a self-explanatory caption, and be on a separate sheet. Authors must submit tables in an editable format and not as images. References to these tables (if any) must be mentioned accurately.

Figures

Figures are supposed to be submitted as separate files. Always include a citation in the text for each figure using Arabic numbers, e.g., Fig. 4. Artwork must be submitted online in vector electronic form or by emailing it.

Preparation of Eletronic Figures for Publication

Although low-quality images are sufficient for review purposes, print publication requires high-quality images to prevent the final product being blurred or fuzzy. Submit (possibly by e-mail) EPS (line art) or TIFF (halftone/ photographs) files only. MS PowerPoint and Word Graphics are unsuitable for printed pictures. Avoid using pixel-oriented software. Scans (TIFF only) should have a resolution of at least 350 dpi (halftone) or 700 to 1100 dpi (line drawings). Please give the data for figures in black and white or submit a Color Work Agreement form. EPS files must be saved with fonts embedded (and with a TIFF preview, if possible).

For scanned images, the scanning resolution at final image size ought to be as follows to ensure good reproduction: line art: >650 dpi; halftones (including gel photographs): >350 dpi; figures containing both halftone and line images: >650 dpi.

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Tips for Writing a Good Quality Engineering Research Paper

Techniques for writing a good quality engineering research paper:

1. Choosing the topic: In most cases, the topic is selected by the interests of the author, but it can also be suggested by the guides. You can have several topics, and then judge which you are most comfortable with. This may be done by asking several questions of yourself, like "Will I be able to carry out a search in this area? Will I find all necessary resources to accomplish the search? Will I be able to find all information in this field area?" If the answer to this type of question is "yes," then you ought to choose that topic. In most cases, you may have to conduct surveys and visit several places. Also, you might have to do a lot of work to find all the rises and falls of the various data on that subject. Sometimes, detailed information plays a vital role, instead of short information. Evaluators are human: The first thing to remember is that evaluators are also human beings. They are not only meant for rejecting a paper. They are here to evaluate your paper. So present your best aspect.

2. Think like evaluators: If you are in confusion or getting demotivated because your paper may not be accepted by the evaluators, then think, and try to evaluate your paper like an evaluator. Try to understand what an evaluator wants in your research paper, and you will automatically have your answer. Make blueprints of paper: The outline is the plan or framework that will help you to arrange your thoughts. It will make your paper logical. But remember that all points of your outline must be related to the topic you have chosen.

3. Ask your guides: If you are having any difficulty with your research, then do not hesitate to share your difficulty with your guide (if you have one). They will surely help you out and resolve your doubts. If you can't clarify what exactly you require for your work, then ask your supervisor to help you with an alternative. He or she might also provide you with a list of essential readings.

4. Use of computer is recommended: As you are doing research in the field of research engineering then this point is quite obvious. Use right software: Always use good quality software packages. If you are not capable of judging good software, then you can lose the quality of your paper unknowingly. There are various programs available to help you which you can get through the internet.

5. Use the internet for help: An excellent start for your paper is using Google. It is a wondrous search engine, where you can have your doubts resolved. You may also read some answers for the frequent question of how to write your research paper or find a model research paper. You can download books from the internet. If you have all the required books, place importance on reading, selecting, and analyzing the specified information. Then sketch out your research paper. Use big pictures: You may use encyclopedias like Wikipedia to get pictures with the best resolution. At Global Journals, you should strictly follow here.

6. Bookmarks are useful: When you read any book or magazine, you generally use bookmarks, right? It is a good habit which helps to not lose your continuity. You should always use bookmarks while searching on the internet also, which will make your search easier.

7. Revise what you wrote: When you write anything, always read it, summarize it, and then finalize it.

8. Make every effort: Make every effort to mention what you are going to write in your paper. That means always have a good start. Try to mention everything in the introduction—what is the need for a particular research paper. Polish your work with good writing skills and always give an evaluator what he wants. Make backups: When you are going to do any important thing like making a research paper, you should always have backup copies of it either on your computer or on paper. This protects you from losing any portion of your important data.

9. Produce good diagrams of your own: Always try to include good charts or diagrams in your paper to improve quality. Using several unnecessary diagrams will degrade the quality of your paper by creating a hodgepodge. So always try to include diagrams which were made by you to improve the readability of your paper. Use of direct quotes: When you do research relevant to literature, history, or current affairs, then use of quotes becomes essential, but if the study is relevant to science, use of quotes is not preferable.

10. Use proper verb tense: Use proper verb tenses in your paper. Use past tense to present those events that have happened. Use present tense to indicate events that are going on. Use future tense to indicate events that will happen in the future. Use of wrong tenses will confuse the evaluator. Avoid sentences that are incomplete.

11. Pick a good study spot: Always try to pick a spot for your research which is quiet. Not every spot is good for studying.

12. Know what you know: Always try to know what you know by making objectives, otherwise you will be confused and unable to achieve your target.

13. Use good grammar: Always use good grammar and words that will have a positive impact on the evaluator; use of good vocabulary does not mean using tough words which the evaluator has to find in a dictionary. Do not fragment sentences. Eliminate one-word sentences. Do not ever use a big word when a smaller one would suffice.

Verbs have to be in agreement with their subjects. In a research paper, do not start sentences with conjunctions or finish them with prepositions. When writing formally, it is advisable to never split an infinitive because someone will (wrongly) complain. Avoid clichés like a disease. Always shun irritating alliteration. Use language which is simple and straightforward. Put together a neat summary.

14. Arrangement of information: Each section of the main body should start with an opening sentence, and there should be a changeover at the end of the section. Give only valid and powerful arguments for your topic. You may also maintain your arguments with records.

15. Never start at the last minute: Always allow enough time for research work. Leaving everything to the last minute will degrade your paper and spoil your work.

16. Multitasking in research is not good: Doing several things at the same time is a bad habit in the case of research activity. Research is an area where everything has a particular time slot. Divide your research work into parts, and do a particular part in a particular time slot.

17. Never copy others' work: Never copy others' work and give it your name because if the evaluator has seen it anywhere, you will be in trouble. Take proper rest and food: No matter how many hours you spend on your research activity, if you are not taking care of your health, then all your efforts will have been in vain. For quality research, take proper rest and food.

18. Go to seminars: Attend seminars if the topic is relevant to your research area. Utilize all your resources.

19. Refresh your mind after intervals: Try to give your mind a rest by listening to soft music or sleeping in intervals. This will also improve your memory. Acquire colleagues: Always try to acquire colleagues. No matter how sharp you are, if you acquire colleagues, they can give you ideas which will be helpful to your research.

20. Think technically: Always think technically. If anything happens, search for its reasons, benefits, and demerits. Think and then print: When you go to print your paper, check that tables are not split, headings are not detached from their descriptions, and page sequence is maintained.

21. Adding unnecessary information: Do not add unnecessary information like "I have used MS Excel to draw graphs." Irrelevant and inappropriate material is superfluous. Foreign terminology and phrases are not apropos. One should never take a broad view. Analogy is like feathers on a snake. Use words properly, regardless of how others use them. Remove quotations. Puns are for kids, not grunt readers. Never oversimplify: When adding material to your research paper, never go for oversimplification; this will definitely irritate the evaluator. Be specific. Never use rhythmic redundancies. Contractions shouldn't be used in a research paper. Comparisons are as terrible as clichés. Give up ampersands, abbreviations, and so on. Remove commas that are not necessary. Parenthetical words should be between brackets or commas. Understatement is always the best way to put forward earth-shaking thoughts. Give a detailed literary review.
22. Report concluded results: Use concluded results. From raw data, filter the results, and then conclude your studies based on measurements and observations taken. An appropriate number of decimal places should be used. Parenthetical remarks are prohibited here. Proofread carefully at the final stage. At the end, give an outline to your arguments. Spot perspectives of further study of the subject. Justify your conclusion at the bottom sufficiently, which will probably include examples.
23. Upon conclusion: Once you have concluded your research, the next most important step is to present your findings. Presentation is extremely important as it is the definite medium though which your research is going to be in print for the rest of the crowd. Care should be taken to categorize your thoughts well and present them in a logical and neat manner. A good quality research paper format is essential because it serves to highlight your research paper and bring to light all necessary aspects of your research.

Informal Guidelines of Research Paper Writing

Key points to remember:

- Submit all work in its final form.
- Write your paper in the form which is presented in the guidelines using the template.
- Please note the criteria peer reviewers will use for grading the final paper.

Final points:

One purpose of organizing a research paper is to let people interpret your efforts selectively. The journal requires the following sections, submitted in the order listed, with each section starting on a new page:

The introduction: This will be compiled from reference matter and reflect the design processes or outline of basis that directed you to make a study. As you carry out the process of study, the method and process section will be constructed like that. The results segment will show related statistics in nearly sequential order and direct reviewers to similar intellectual paths throughout the data that you gathered to carry out your study.

The discussion section:

This will provide understanding of the data and projections as to the implications of the results. The use of good quality references throughout the paper will give the effort trustworthiness by representing an alertness to prior workings.

Writing a research paper is not an easy job, no matter how trouble-free the actual research or concept. Practice, excellent preparation, and controlled record-keeping are the only means to make straightforward progression.

General style:

Specific editorial column necessities for compliance of a manuscript will always take over from directions in these general guidelines.

To make a paper clear: Adhere to recommended page limits.

Mistakes to avoid:

- Insertion of a title at the foot of a page with subsequent text on the next page.
- Separating a table, chart, or figure—confine each to a single page.
- Submitting a manuscript with pages out of sequence.
- In every section of your document, use standard writing style, including articles ("a" and "the").
- Keep paying attention to the topic of the paper.

- Use paragraphs to split each significant point (excluding the abstract).
- Align the primary line of each section.
- Present your points in sound order.
- Use present tense to report well-accepted matters.
- Use past tense to describe specific results.
- Do not use familiar wording; don't address the reviewer directly. Don't use slang or superlatives.
- Avoid use of extra pictures—include only those figures essential to presenting results.

Title page:

Choose a revealing title. It should be short and include the name(s) and address(es) of all authors. It should not have acronyms or abbreviations or exceed two printed lines.

Abstract: This summary should be two hundred words or less. It should clearly and briefly explain the key findings reported in the manuscript and must have precise statistics. It should not have acronyms or abbreviations. It should be logical in itself. Do not cite references at this point.

An abstract is a brief, distinct paragraph summary of finished work or work in development. In a minute or less, a reviewer can be taught the foundation behind the study, common approaches to the problem, relevant results, and significant conclusions or new questions.

Write your summary when your paper is completed because how can you write the summary of anything which is not yet written? Wealth of terminology is very essential in abstract. Use comprehensive sentences, and do not sacrifice readability for brevity; you can maintain it succinctly by phrasing sentences so that they provide more than a lone rationale. The author can at this moment go straight to shortening the outcome. Sum up the study with the subsequent elements in any summary. Try to limit the initial two items to no more than one line each.

Reason for writing the article—theory, overall issue, purpose.

- Fundamental goal.
- To-the-point depiction of the research.
- Consequences, including definite statistics—if the consequences are quantitative in nature, account for this; results of any numerical analysis should be reported. Significant conclusions or questions that emerge from the research.

Approach:

- o Single section and succinct.
- o An outline of the job done is always written in past tense.
- o Concentrate on shortening results—limit background information to a verdict or two.
- o Exact spelling, clarity of sentences and phrases, and appropriate reporting of quantities (proper units, important statistics) are just as significant in an abstract as they are anywhere else.

Introduction:

The introduction should "introduce" the manuscript. The reviewer should be presented with sufficient background information to be capable of comprehending and calculating the purpose of your study without having to refer to other works. The basis for the study should be offered. Give the most important references, but avoid making a comprehensive appraisal of the topic. Describe the problem visibly. If the problem is not acknowledged in a logical, reasonable way, the reviewer will give no attention to your results. Speak in common terms about techniques used to explain the problem, if needed, but do not present any particulars about the protocols here.

The following approach can create a valuable beginning:

- o Explain the value (significance) of the study.
- o Defend the model—why did you employ this particular system or method? What is its compensation? Remark upon its appropriateness from an abstract point of view as well as pointing out sensible reasons for using it.
- o Present a justification. State your particular theory(-ies) or aim(s), and describe the logic that led you to choose them.
- o Briefly explain the study's tentative purpose and how it meets the declared objectives.

Approach:

Use past tense except for when referring to recognized facts. After all, the manuscript will be submitted after the entire job is done. Sort out your thoughts; manufacture one key point for every section. If you make the four points listed above, you will need at least four paragraphs. Present surrounding information only when it is necessary to support a situation. The reviewer does not desire to read everything you know about a topic. Shape the theory specifically—do not take a broad view.

As always, give awareness to spelling, simplicity, and correctness of sentences and phrases.

Procedures (methods and materials):

This part is supposed to be the easiest to carve if you have good skills. A soundly written procedures segment allows a capable scientist to replicate your results. Present precise information about your supplies. The suppliers and clarity of reagents can be helpful bits of information. Present methods in sequential order, but linked methodologies can be grouped as a segment. Be concise when relating the protocols. Attempt to give the least amount of information that would permit another capable scientist to replicate your outcome, but be cautious that vital information is integrated. The use of subheadings is suggested and ought to be synchronized with the results section.

When a technique is used that has been well-described in another section, mention the specific item describing the way, but draw the basic principle while stating the situation. The purpose is to show all particular resources and broad procedures so that another person may use some or all of the methods in one more study or referee the scientific value of your work. It is not to be a step-by-step report of the whole thing you did, nor is a methods section a set of orders.

Materials:

Materials may be reported in part of a section or else they may be recognized along with your measures.

Methods:

- Report the method and not the particulars of each process that engaged the same methodology.
- Describe the method entirely.
- To be succinct, present methods under headings dedicated to specific dealings or groups of measures.
- Simplify—detail how procedures were completed, not how they were performed on a particular day.
- If well-known procedures were used, account for the procedure by name, possibly with a reference, and that's all.

Approach:

It is embarrassing to use vigorous voice when documenting methods without using first person, which would focus the reviewer's interest on the researcher rather than the job. As a result, when writing up the methods, most authors use third person passive voice.

Use standard style in this and every other part of the paper—avoid familiar lists, and use full sentences.

What to keep away from:

- Resources and methods are not a set of information.
- Skip all descriptive information and surroundings—save it for the argument.
- Leave out information that is immaterial to a third party.

Results:

The principle of a results segment is to present and demonstrate your conclusion. Create this part as entirely objective details of the outcome, and save all understanding for the discussion.

The page length of this segment is set by the sum and types of data to be reported. Use statistics and tables, if suitable, to present consequences most efficiently.

You must clearly differentiate material which would usually be incorporated in a study editorial from any unprocessed data or additional appendix matter that would not be available. In fact, such matters should not be submitted at all except if requested by the instructor.

Content:

- Sum up your conclusions in text and demonstrate them, if suitable, with figures and tables.
- In the manuscript, explain each of your consequences, and point the reader to remarks that are most appropriate.
- Present a background, such as by describing the question that was addressed by creation of an exacting study.
- Explain results of control experiments and give remarks that are not accessible in a prescribed figure or table, if appropriate.
- Examine your data, then prepare the analyzed (transformed) data in the form of a figure (graph), table, or manuscript.

What to stay away from:

- Do not discuss or infer your outcome, report surrounding information, or try to explain anything.
- Do not include raw data or intermediate calculations in a research manuscript.
- Do not present similar data more than once.
- A manuscript should complement any figures or tables, not duplicate information.
- Never confuse figures with tables—there is a difference.

Approach:

As always, use past tense when you submit your results, and put the whole thing in a reasonable order.

Put figures and tables, appropriately numbered, in order at the end of the report.

If you desire, you may place your figures and tables properly within the text of your results section.

Figures and tables:

If you put figures and tables at the end of some details, make certain that they are visibly distinguished from any attached appendix materials, such as raw facts. Whatever the position, each table must be titled, numbered one after the other, and include a heading. All figures and tables must be divided from the text.

Discussion:

The discussion is expected to be the trickiest segment to write. A lot of papers submitted to the journal are discarded based on problems with the discussion. There is no rule for how long an argument should be.

Position your understanding of the outcome visibly to lead the reviewer through your conclusions, and then finish the paper with a summing up of the implications of the study. The purpose here is to offer an understanding of your results and support all of your conclusions, using facts from your research and generally accepted information, if suitable. The implication of results should be fully described.

Infer your data in the conversation in suitable depth. This means that when you clarify an observable fact, you must explain mechanisms that may account for the observation. If your results vary from your prospect, make clear why that may have happened. If your results agree, then explain the theory that the proof supported. It is never suitable to just state that the data approved the prospect, and let it drop at that. Make a decision as to whether each premise is supported or discarded or if you cannot make a conclusion with assurance. Do not just dismiss a study or part of a study as "uncertain."

Research papers are not acknowledged if the work is imperfect. Draw what conclusions you can based upon the results that you have, and take care of the study as a finished work.

- You may propose future guidelines, such as how an experiment might be personalized to accomplish a new idea.
- Give details of all of your remarks as much as possible, focusing on mechanisms.
- Make a decision as to whether the tentative design sufficiently addressed the theory and whether or not it was correctly restricted. Try to present substitute explanations if they are sensible alternatives.
- One piece of research will not counter an overall question, so maintain the large picture in mind. Where do you go next? The best studies unlock new avenues of study. What questions remain?
- Recommendations for detailed papers will offer supplementary suggestions.

Approach:

When you refer to information, differentiate data generated by your own studies from other available information. Present work done by specific persons (including you) in past tense.

Describe generally acknowledged facts and main beliefs in present tense.

The Administration Rules

Administration Rules to Be Strictly Followed before Submitting Your Research Paper to Global Journals Inc.

Please read the following rules and regulations carefully before submitting your research paper to Global Journals Inc. to avoid rejection.

Segment draft and final research paper: You have to strictly follow the template of a research paper, failing which your paper may get rejected. You are expected to write each part of the paper wholly on your own. The peer reviewers need to identify your own perspective of the concepts in your own terms. Please do not extract straight from any other source, and do not rephrase someone else's analysis. Do not allow anyone else to proofread your manuscript.

Written material: You may discuss this with your guides and key sources. Do not copy anyone else's paper, even if this is only imitation, otherwise it will be rejected on the grounds of plagiarism, which is illegal. Various methods to avoid plagiarism are strictly applied by us to every paper, and, if found guilty, you may be blacklisted, which could affect your career adversely. To guard yourself and others from possible illegal use, please do not permit anyone to use or even read your paper and file.

Criterion for Grading a Research Paper (Compilation) by Global Journals

Please note that following table is only a Grading of "Paper Compilation" and not on "Performed/Stated Research" whose grading solely depends on Individual Assigned Peer Reviewer and Editorial Board Member. These can be available only on request and after decision of Paper. This report will be the property of Global Journals.

Topics	Grades		
	A-B	**C-D**	**E-F**
Abstract	Clear and concise with appropriate content, Correct format. 200 words or below	Unclear summary and no specific data, Incorrect form Above 200 words	No specific data with ambiguous information Above 250 words
Introduction	Containing all background details with clear goal and appropriate details, flow specification, no grammar and spelling mistake, well organized sentence and paragraph, reference cited	Unclear and confusing data, appropriate format, grammar and spelling errors with unorganized matter	Out of place depth and content, hazy format
Methods and Procedures	Clear and to the point with well arranged paragraph, precision and accuracy of facts and figures, well organized subheads	Difficult to comprehend with embarrassed text, too much explanation but completed	Incorrect and unorganized structure with hazy meaning
Result	Well organized, Clear and specific, Correct units with precision, correct data, well structuring of paragraph, no grammar and spelling mistake	Complete and embarrassed text, difficult to comprehend	Irregular format with wrong facts and figures
Discussion	Well organized, meaningful specification, sound conclusion, logical and concise explanation, highly structured paragraph reference cited	Wordy, unclear conclusion, spurious	Conclusion is not cited, unorganized, difficult to comprehend
References	Complete and correct format, well organized	Beside the point, Incomplete	Wrong format and structuring

Index

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