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Method to Determine the Delay between Measurements in two or more Spectrum Analyzers or Power Meters

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Abstract: The aim is to compute the time delay between the set of measurements in each of two or more Spectrum Analyzers using a linear relation between two dimensions (power and time). This method of time measurement implies to input in each Spectrum Analyzer two identical and synchronized Amplitude Shift Keying signals, each one modulated by a square wave of duty cycle of 50%. It is also valid with Direct Current. Instead of an input of an Amplitude Shift Keying signal (Radio Frequency /Microwaves) it is input a square wave and the power is measured with a Direct Current power meter with trigger.

Keyword: Amplitude Shift Keying (ASK), Direct Current, Power Meter, trigger by software, trigger by hardware, Spectrum Analyzer (SA), Spectrum Occupancy, Fusion

1. INTRODUCTION

The present invention is related with the computation of the time difference, between the start of the set of measurements of power (in one sweep) in two or more Spectrum Analyzers triggered by hardware, software or mix. The time difference is computed from the power measurement sets of the SAs. The difference between the time delays of the triggers on the SAs is the computed time. Those delay differences may be due to the hardware or software of the Spectrum Analyzers or because the signals of the triggers are not synchronized at first place.

In case of SAs with precise timings, this method can be used for computing the difference of delays of the signals of trigger generated by external circuits. That can be used, for example, to measure the difference of transmission time in two transmission lines or absolute transmission time in a single one and by that way to measure the length of a transmission line. It also allows measuring the degree of synchronization between simultaneous measurements in multiple SAs.

In order to verify the method or in other applications of the method, the SAs can be replaced by other power meters of Radio Frequency, Microwave or Direct Current, (DC) all with triggers.

This method of measurement implies the input of identical synchronous Amplitude Shift Keying signals resulted from the modulation of a carrier by a square wave of 50% duty cycle.

If the SAs are located far apart from each other the ASK signals must be synchronized in some way, *i.e.*, by Global Positioning System (GPS). If co-located, a common ASK signal can be split in equally powered signals by a signal splitter/divisor. The method permits the correction of the computed time difference in case the ASK signals do not have the same measured power due to calibration errors on the SAs or unbalanced signal division on the splitter. The computed signal, from all sweep points, representing time, shows a good precision, in case of having a periodic maximum top flatness representing the true delay difference. That precision happens when the period of time computed is much greater than the temporal imprecisions of the instruments, and in the case of the computed time be about the period of the ASK signal divided by 4. The method is also applicable in DC with a positive square wave with duty cycle of 50% and with DC power meters with trigger. All the theory is applicable the same way.

In Section 2 is presented the functionality of the main apparatus of this work, the Spectrum Analyzer. The main theoretical work, which final result is the computed time equation, is presented in Section 3. In Section 4, the theoretical determination of the precision of the method is done. In Section 5, the applicability of the method is presented. The experiment to test the method is described in Section 6. The results obtained by applying the method are presented in Section 7. Finally, the conclusions are outlined in Section 8.

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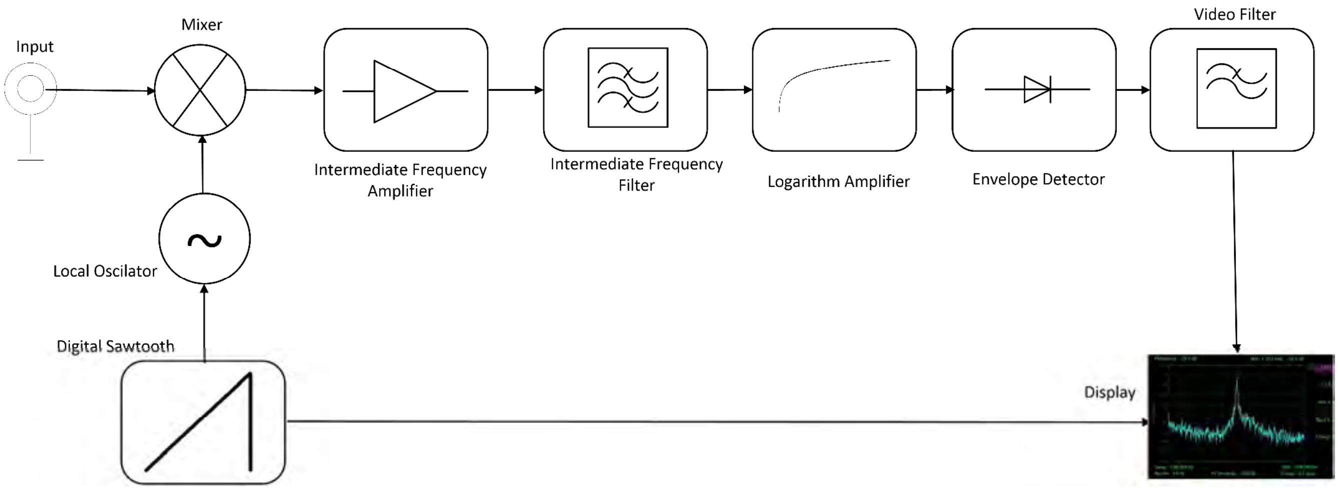

Figure 1 Heterodyne Spectrum Analyzer

2. SPECTRUM ANALYZERS

The main component of the measuring setup in this work is the Spectrum Analyzer. This section will give insight about this apparatus. Figure 1 shows a simplified conceptual schematic of a heterodyne Spectrum Analyzer used in this work. The information on the input signal's level is contained in the level (in its envelope) of the Intermediate Frequency (IF) signal. For this reason, after Intermediate Frequency Filter (Resolution Filter with Resolution Bandwidth (RBW)) be performed, this IF signal's envelope is determined. The procedure for doing this is comparable to the demodulation of an AM signal, which means that it is possible, for instance, to employ an analog envelope demodulator. The filtered IF signal is rectified and the RF signal components can be eliminated by a lowpass filter named Video Filter. After the envelope smoothed by the Video Filter, it is displayed **[1]**. The logarithm filter before the rectifier permits to increase the range of the signal to be displayed.

In modern Spectrum Analyzers the signal is sampled at Intermediate Frequency and all forward processing is done digitally. Before sampling the Spectrum Analyzer has several cascaded Intermediate Frequency stages, with decreased IF thru that chain.

Then it is enumerated the main parameters to set in a Spectrum Analyzer

- Number of equal spaced frequency points of the sweep: This is a setting that only can take some predefined values (*i.e.* 501, 1001, 2001, later represented by *I* points). Usually is an odd number to include both limits of the band. In this work, a set of *I* sweep points is named as a *section*.
- Pair: Start and Stop Frequency (StartBand and StopBand respectively) or Pair: Center Frequency and Frequency Span (CenterFrequency and SPAN respectively). Determines the bandwidth in which the sweep points are spanned.

  $$StartBAND = CenterFreq - SPAN/2 \quad , \quad StopBAND = CenterFreq + SPAN/2$$

  In case of SPAN=0 all measurements points are made at the same frequency
- Resolution Bandwidth (RBW) . Bandwidth of the measurement in turn of the frequency of the sweep point. Better practice is to made

  $$(I-1)*RBW = StopBAND - StartBAND$$
- Video Bandwidth (VBW) – Filter to smooth the IF envelope. Must be, in our case, 3-10 times the bandwidth of the Resolution Filter.
- Sweep Time – It is the accumulated time of the measurements, in all sweep points. It takes in account the settling times of the filters (RBW Filter and VBW Filter). Then the sweep time in each point is not the total sweep time divided by the number of sweep points. That only happens for SPAN=0.
- Detector Type (*i.e.* RMS) The detector used in this work is the RMS that gives information of the power.

3. DETAILED DESCRIPTION OF THE INVENTION

In Figure 2, one example of a setup for indirect measurement of the time difference between the start time of the measurements (A8) of two SAs (B4 and B5, Figure 2, Figure 3, Figure 4) is shown. In this setup (Figure 2), the trigger is made by hardware in one SA and in software in the other. The time instant of the start of the measurement, in the SA with trigger by hardware is deterministic. In the SA with trigger by software the instant of time of measurement start is randomness.

In Figure 3, the setup with two SAs triggered by software (triggered through commands transmitted through Ethernet) and in Figure 4, another setup with two SAs triggered by hardware (with the trigger inputs), from one Card commanded and Power supplied by USB (Universal Serial Bus) with digital TTL outputs (B8, acronym CARD) are shown. The Card is programmed by USB by a Portable Computer (B1).

In each SA, one ASK signal of equal power (which are not really equal due to asymmetries in the signal splitter) is injected thru a Signal Splitter (B3). The measurement is made with the SAs central frequency setting equal to the carrier frequency and SPAN equal to zero. The Resolution Bandwidth setting in the SAs must be such that it includes in excess the bandwidth of the ASK signal which it must be determined from visualization of the ASK signal in the SA, with adequate SPAN and Resolution bandwidth.

In Figure 5, the ASK wave with two time measurement windows of power, each representing one point of the sweep in each SA, is shown.

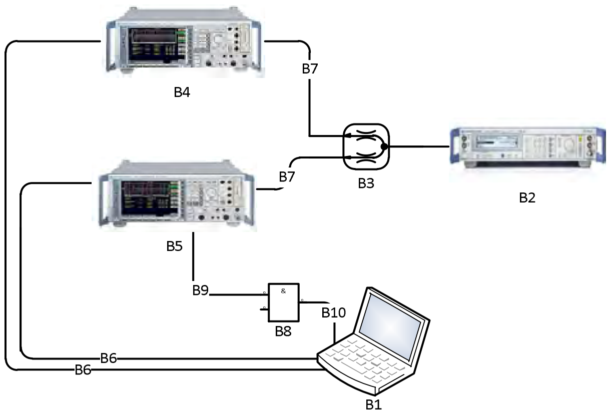

Figure 2 Measurement Setup 1 (one), B1– Portable Computer, B2 – Signal Generator (ASK generator), B3 – Signal Splitter, B4, B5 – Spectrum Analyzers, B6 – Ethernet Connection (Double Port Ethernet Card), B7 – SMA Cable, B8 – Card of TTL digital outputs commanded and Power supplied by USB (Universal Serial Bus), B9 – Cable connected to the trigger input of the Spectrum Analyzer, B10 – USB Cable.

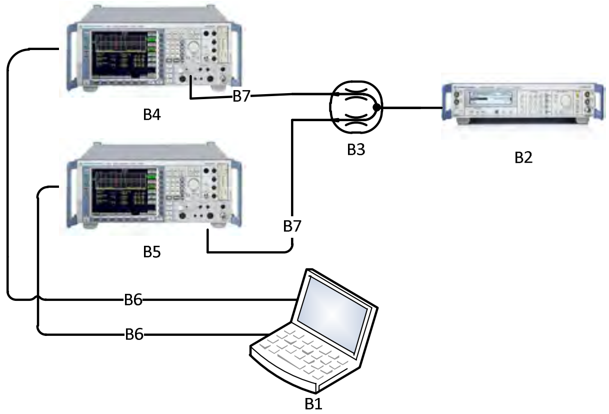

Figure 3 Measurement Setup 2 (two), B1 – Portable Computer, B2 – Signal Generator (ASK generator), B3 – Signal Splitter, B4,B5 – Spectrum Analyzers, B6 – Ethernet Connection (Double Port Ethernet Card), B7 – SMA Cable

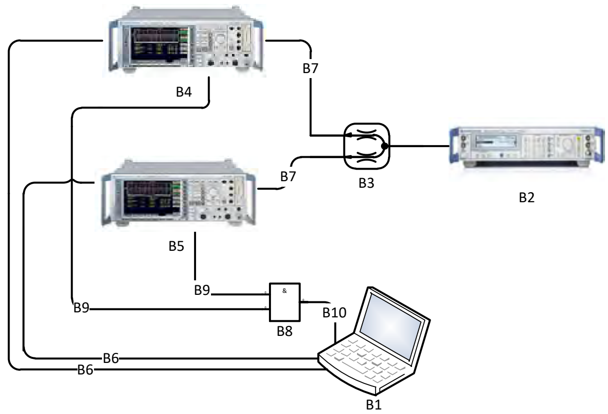

Figure 4 Measurement Setup 3 (three), B1 – Portable Computer, B2 – Signal Generator (ASK generator), B3 – Signal Splitter, B4,B5 – Spectrum Analyzers, B6 – Ethernet Connection (Double Port Ethernet Card), B7 – SMA Cable, B8 – Card of TTL digital outputs commanded and Power supplied by USB (*Universal Serial Bus*), B9 – Cable connected to the trigger input of the Spectrum Analyzer, B10 – USB Cable

Initially, the sweep point time (T_{sw_p}, A7) is set as half of the period of the ASK signal ($T_{ASK}/2$, A9). Notice that in each SA the sweep time will be the number of sweep points multiplied by such time ($T_{ASK}/2$, A9). For SPAN equal to zero the settling times of the Resolution and Video Filters are zero [2] in page 76.

In approximation it can be considered that at each sweep point the SA measures the energy and then it is divided by the interval of time of the measurement to compute the power.

In this case, the value of the time difference in the SAs (given in Figure 5 by T_{Δ_i}, A8) is linearly related to the Energy difference between them (as states Figure 5). In this perfect scenario, with $T_{sw\_p} = T_{ASK}/2$, from each sweep point is obtained the same result for T_{Δ_i} for all *i*. The wave representing time computed from all sweep points is a flat line.

T_{Δ_i} corresponds to the energy $T_{sw\_p}\left|P^i_{SA_1}-P^i_{SA_2}\right|$, $T_{ASK}/2$ corresponds to energy $T_{ASK}P_{ASK}$:

$$T_{\Delta_i}=\frac{T_{sw\_p}\left|P^i_{SA_1}-P^i_{SA_2}\right|}{T_{ASK}P_{ASK}}\frac{T_{ASK}}{2}=\frac{\left|P^i_{SA_1}-P^i_{SA_2}\right|}{2P_{ASK}}T_{sw\_p} \qquad (1)$$

where $P^i_{SA_1}$ and $P^i_{SA_2}$ are the measured powers (linear, if the measurements are made in a logarithm scale as dBm they must be converted to Watt) in each sweep point *i* in each SA (SA_1 and SA_2, B4 and B5). P_{ASK} is the power of the ASK signal injected in each SA. The other variables are displayed in Figure 5.

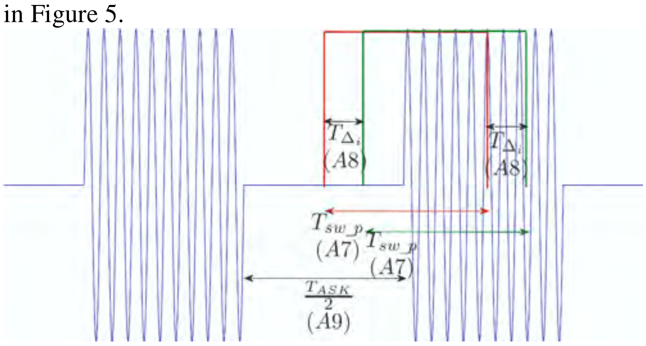

Figure 5 Rectangles – Measurement temporal Windows in two SAs in one point of the sweep, Sine wave of 50% Duty Cycle – ASK Signal.

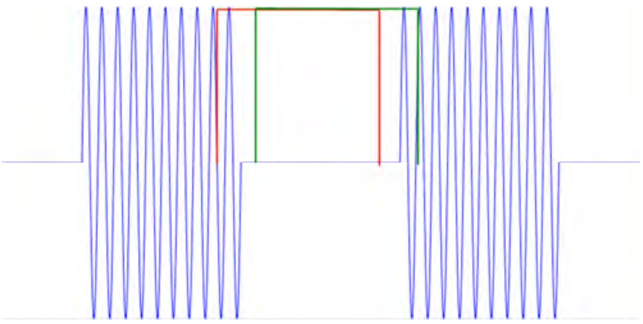

Figure 6 Case in which T_{Δ_i} is about zero for all i.

It may happen that the relative time phase of the measurements to be of Figure 6 and in that case the power difference and computed time is zero for all *i*. One way to solve this problem is to make the measurement time in each sweep point slightly greater than half period of ASK signal in such way that the relative time phase will change through the sweep points. The time between time instants of the start of the measurement in the two SAs continues to be given by Equation 1. The value of Equation 1 through *i* index of the sweep points changes periodically from zero to a maximum, differently from before in which the values kept constant. The maximum is the difference between the time instants.

P_{ASK} can be directly measured in each sweep *section* (because $T_{sw\_p}>T_{ASK}/2$). There is a equality relation of the measured energy $T_{sw\_p}\underset{i\in\{1,\dots,I\}}{\mathrm{MAX}}(P^i_{SA_1})$ and the energy of the ASK wave which gives

$$P_{ASK}=\frac{T_{sw\_p}\underset{i\in\{1,\dots,I\}}{\mathrm{MAX}}(P^i_{SA_1})}{T_{ASK}} \qquad (2)$$

where $\underset{i\in\{1,\dots,I\}}{\mathrm{MAX}}(P^i_{SA_1})$ represents the maximum of the measured power in each *section* in the SA_1 (the SA chosen is irrelevant).

From here on, $i\in\{1,\dots,I\}$ will be omitted from the equations.

Different calibration errors on the SAs and unbalanced attenuations in the signal splitter can be compensated (it is important to compensate one SA in relation to the other because the real values of variables involved are not available) with the following gain in power in the SA_2

$$G_{\Delta}=\frac{\mathrm{MAX}(P^i_{SA_1})}{\mathrm{MAX}(P^i_{SA_2})} \qquad (3)$$

Replacing Equation 2 in Equation 1 and replacing the Equation 3 in Equation 1 it is obtained

$$T_{\Delta_i}=\frac{\left|P^i_{SA_1}-P^i_{SA_2}G_{\Delta}\right|}{\mathrm{MAX}(P^i_{SA_1})}\frac{T_{ASK}}{2} \qquad (4)$$

In the expression $\left|P^i_{SA_1}-P^i_{SA_2}G_{\Delta}\right|/\mathrm{MAX}(P^i_{SA_1})$, the calibration errors of SA_1 are cancelled if the error is modelled with a gain.

4. PRECISION OF THE METHOD

The relative error of function F , in function of the errors of its variables, is given by

$$\frac{\Delta F}{F\left(x_1,x_2,\dots.x_n\right)}=\frac{\sum_{j=1}^{n}\frac{dF}{dx_j}\Delta x_j}{F\left(x_1,x_2,\dots.x_n\right)} \qquad (5)$$

Thus, if there is a high precision the variables involving time and $P^i_{AS_1}-P^i_{AS_2}G_{\Delta}>0$ is reached to absolute error on computing the time difference

$$\Delta T_{\Delta_i}=\frac{T_{ASK}}{2}\frac{P^i_{SA_1}\left(\varepsilon_{11}-\varepsilon_{12}\right)}{\mathrm{MAX}\left(P^i_{SA_1}\right)}+\frac{T_{ASK}}{2}\frac{P^i_{SA_2}\left(\varepsilon_{22}-\varepsilon_{21}\right)}{\mathrm{MAX}\left(P^i_{SA_2}\right)} \qquad (6)$$

where ε_{11} - Relative Error in the measurement of $P^i_{SA_1}$, ε_{12} - Relative Error in the measurement of $MAX\left(P^i_{SA_1}\right)$, ε_{21} - Relative Error in the measurement of $P^i_{SA_2}$, ε_{22} - Relative Error in the measurement of $MAX\left(P^i_{SA_2}\right)$.

Notice that in the same SA, the relative error can have the same signal and thus it can be an error cancellation effect.

Considering that the standard deviation of the relative error of measured power in the SAs is ε_r (best case [3], [4] typically 1.5%/100, but it was found in internet sites reporting errors as low as 0.4%) and for the worst case $\varepsilon_{12} = -\varepsilon_{11} = -\varepsilon_r$ and $\varepsilon_{21} = -\varepsilon_{22} = -\varepsilon_r$ thus

$$\left|\Delta T_{\Delta_i}\right| = \varepsilon_r T_{ASK}\left(\frac{P^i_{SA_1}}{\text{MAX}\left(P^i_{SA_1}\right)} + \frac{P^i_{SA_2}}{\text{MAX}\left(P^i_{SA_2}\right)}\right) \tag{7}$$

$$\frac{\left|\Delta T_{\Delta_i}\right|}{T_{\Delta_i}} = 2\varepsilon_r\left(\frac{P^i_{SA_1}\text{MAX}\left(P^i_{SA_2}\right) + P^i_{SA_2}\text{MAX}\left(P^i_{SA_1}\right)}{\left|P^i_{SA_1}\text{MAX}\left(P^i_{SA_2}\right) - P^i_{SA_2}\text{MAX}\left(P^i_{SA_1}\right)\right|}\right) \tag{8}$$

The theoretical relative error given by Equation 8, with $T_{ASK}/2 \cong 2T_\Delta$, being T_Δ the difference of time instants of the start of measurements (A8), is approximately 5% (for 1.5% of relative error of the power measurements). This is the worst case. Also the real relative error can be smaller if it is a cancelling effect of the error or if the precision of the SAs are better. The precision decreases with the increase of $T_{ASK}/2$ (A9) in relation to $2T_\Delta$. $T_{ASK}/2$ (A9) must be chosen big enough in order to compute the time instants difference expected but not too much in order to guarantee the precision. It is recommended that

$$\begin{gathered} T_\Delta < \tfrac{1}{2}\left(T_{ASK} - T_{sw\_p}\right) \\ T_{sw\_p} = \frac{T_{ASK}}{2}\left(1 + \frac{\delta}{100}\right) \\ \delta > 5 \\ \delta < 15 \end{gathered} \tag{9}$$

This set of Equations 9 calculates the period of ASK wave in function of the time to be computed. By Equations 9 the time to be computed must be smaller than approximately one quarter of the period of the ASK wave.

δ is a parameter which defines the percentage in which the point sweep time is greater to half of the period of the ASK wave. As defined by Equations 9 it is recommended that this percentage to be between 5 and 15.

These simultaneous conditions, expressed by Equations 9, guarantees that the waves presented in the Results (Section 7), have sufficiently large tops.

5. APPLICATION EXAMPLES

In the study of signal fusion in Cognitive Radio is necessary to do synchronous power measurements with two positions separated two hundred meters between measurement sets in order to measure shadow conditions. This is the follow up of measurement with a single setup [5] of Spectrum Occupancy with Global System for Mobile communications (GSM) bands. In Figure 7, the measurement campaign scenario for Cognitive Radio is shown. $P(t, s_1)$ (A5) is the power measured in SA_1 .

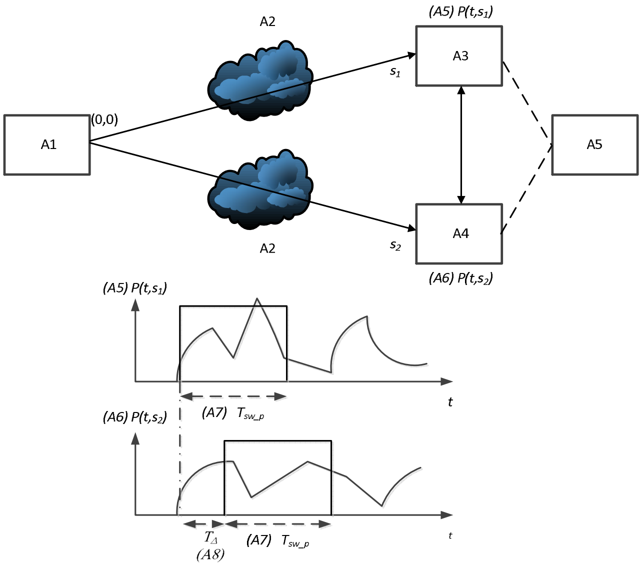

Figure 7 Measurement Campaign Scenario for Cognitive Radio. A1 – Base Station, A2 – Obstacles, A3 - Sensor (SA_1) with $P(t,s_1)$, A4 - Sensor (SA_2) with $P(t,s_2)$, A5 – Computer. The distance between sensors is less than 200 meters.

Each rectangle shows the temporal window of a sweep point measurement. For the measurements to be useful it is necessary that they are synchronized on the two or more SAs. The difference between time instants T_Δ (A8) is found with the proposed method. To obtain a good synchronism it is needed that $T_\Delta \ll T_{sw\_fusion}$ ([1] T_{sw_fusion} - measurement time period in each sweep point to do later the fusion). In [5] the sweep point time was 4.62ms, equal to the time of one frame of GSM. It was found that the time period between the start of the measurements in the SAs with hardware triggers (T_Δ , A8) was about $8\mu s$ which it is a good synchronism for the sweep point time equal to the GSM

[1] Do not make confusion with the sweep point time in the method to compute T_Δ (A8).

frame. This repeatable $8\mu s$ can be compensated with a manual command or by a software command doing a delay to the response to the trigger on the SA in advance.

Previous work on Spectrum Occupancy, with or without data fusion, was made by synchronism obtained by GPS [6] which it does not permit flexibility in the choice of the sweep time and it does not permit continuous measurements without time lapses. In other cases, the time measurement is made in computer networks, usually back to back in Media Access Control (MAC) layer and it involves considerable technological resources [7], [8]. In our case the method simplifies because the original system includes SAs that can measure power with precision.

This invention might origin Application Notes for brands of SAs as Rohde-Schwarz, Keysight, Tektronix, etc. One group of companies that can be interested in the industrialization of the invention are manufacturers of instruments to measure the delay difference in two (or more) transmissions lines. It can also measure absolute delays in transmission lines if one Input/Output TTL line is connected directly to the trigger of one SAs (or power meter) and the other Input/Output TTL line is connected to the transmission line in which the delay must be measured. This delay can be used to measure the length of transmission lines.

The invention can be enlarged to include Power Meters in Direct Current, with a squared wave instead the ASK wave. Thus, much more companies can be interested. A Power Meter of Direct Current has a much simpler technology and it broadens the applicability.

6. DESCRIPTION OF THE EXPERIMENT WITH TRIGGER BY HARDWARE IN BOTH SPECTRUM ANALYSERS

Mount the setup of Figure 4.

In the extremities of RG58 Cables (B9, Figure 4), each one with 90 meters, do the connections of Figure 8. The shield of the RG58 cable is connected to the 0V of the CARD (I3, Figure 8). In the SAs sides the shield is connected to the external of the connector of the trigger input (I4, Figure 8). Both cable terminations are protected from overshoot and undershoot voltages, with Schottky Diodes (I1, I2, I5, Figure 8) and one Zener Diode (I6, Figure 8). In the CARD (B8) side (L1, Figure 8) are protected with two Schottky Diodes (I1, I2, Figure 8, BAT85S model) because there is access to the Power Supply connections. In the SAs sides (triggers inputs, L2, Figure 8) are protected with Schottky Diode (I5, Figure 8) and a Zener Diode (I6, Figure 8, BZX79–C5V6 model) because there is no access to the higher voltage of Power Supply of the SAs.

Program manually the signal generator (B2, R&S, SMU200A, R&S®SMU-B9/-B10/-B1 options) to generate the ASK wave with the pretended period, changing the rate of Symbols/Bits in the Baseband Block. Greater periods of the modulating squared wave can be obtained with Data Patterns (selecting Patterns in Baseband window) with consecutive 1s, followed by consecutive 0s. The period of ASK wave can be found by Equations 9.

Not known in advance the time to compute T_{Δ}, the ASK signal period (T_{ASK}) must be tried till the right measurement is achieved. T_{ASK} must be chosen in order to compute in excess the expected time. One way to test the period of the ASK signal (T_{ASK}), it is to change it one small percentage and if it gives a different computed time it is because T_{ASK} is not the right one yet.

Program also the ASK modulation on the signal generator, ASK modulation index of 100%, rectangular filter in baseband with internal clock and internal data. In the Radio Frequency (RF) section of the signal generator define the carrier frequency, and the power level of the carrier in order that all the signal (total power, including all the bandwidth of the ASK signal) to be at least 30dB higher than the noise power, but not too high in order to respect the linear response of the SAs, signal generator and splitter.

Run the Labview program in the Portable Computer (B1) to program the SAs (B4, B5. Rhode & Schwarz, FSP40 and FSQ8 models) with the sweep time (T_{sw_p} times the number of sweep points), number of sweep points (this parameter can only take certain values determined by SAs maker), RMS measurements, SPAN=0, carrier frequency, resolution bandwidth (measure previously manually the bandwidth of the signal ASK with a SA, with the setting SPAN different from zero) and the video bandwidth (3-10 times the measurement bandwidth) and put the SAs in waiting mode of a hardware trigger. This programming is done by the Portable Computer through two Ethernet Cables (B6, STP – Shielded Twisted Pair, direct connection without repeaters) with more than 90 meters (< 100 meters), one to each SA. In the Portable Computer side there is a double Ethernet Card (with two ports, 100BaseT).

Then the Labview program switches simultaneous the two lines of Output TTL (B8, same byte Output) of the CARD (with Push-Pull outputs), from approximately 0V to 5V. The two SAs must do the measurement due to the trigger (signal trough RG58 cables, D9). The voltage level in which the SAs do the trigger must be equal in both SAs and in the Positive Edge or Negative Edge (in this case the switch must be done from 5V to 0V) in both.

Read the measurements (group of sweep points, named as *sections*, in floating point format) from the SAs through the Ethernet connections, to the Portable Computer and save them to the disk.

Compute Equation 4 for each sweep point and obtain each *section* of Figure 10 ahead (using all the points). It can be used the same Portable Computer that it reads the measurements from the SAs to make the computations and generate the graphics with a program as the Matlab.

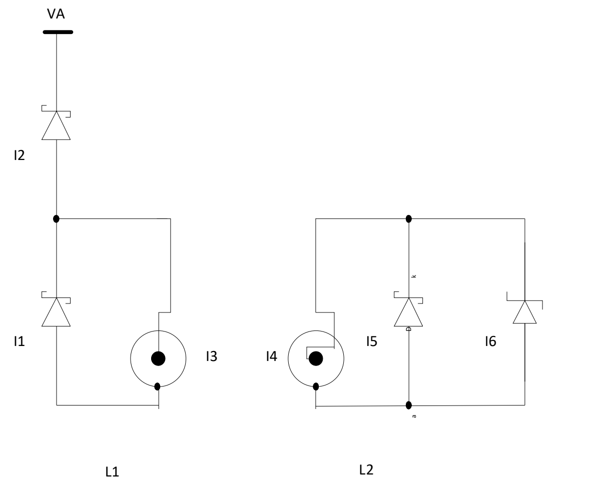

Figure 8 Connections of the Zener Diode and Schottky Diodes for the voltage limitation in both ends of the cable RG58 in which is transmitted the trigger signal. I1,I2,I5 – Schottky Diodes, I6 – Zener Diode, I3,I4 – Endings of RG58 cables. L1 – Card of TTL digital outputs commanded and Power supplied by USB (*Universal Serial Bus*) end side, L2 – Spectrum Analyser end side, VA – 5 Volts from Card commanded and Power supplied by USB (*Universal Serial Bus*) of TTL digital outputs.

The measurements can be made with more than 2 SAs (*n* SAs). Thus it is generated the trigger in *n* > 2 TTL Outputs (the signal splitter has *n* outputs also). Read the measurement sets with *n* Ethernet Cables connected to *n* SAs. But the computations are made in groups of 2 measurements (sets) (2 at a time) from 2 SAs until cover all SAs.

7. RESULTS

In Figure 9, several *sections*, each representing one sweep, of computed time difference from power measurements in two SAs (B4, B5) triggered by software (scenario of Figure 3) are presented. It represents four *sections* of 501 sweep points each. The parameters are $T_{sw\_p} = 21ms$, $T_{ASK} = 40ms$ and $P_{ASK} = 0.44\mu W$ ($-33.56dBm$). As it can be seen, the difference of time instants (A8) is given by the maximum which does not change during one *section*. The real relative error can be considered small taking in consideration the flat tops of the *section* waves. No repeatable computed times (in different *sections*) can be due to time differences in the processing on the SAs and lack of synchronism sending the commands, through Ethernet Cables (B6), by the computer.

Figure 10 shows the measures in a scenario of two SAs (B4, B5) triggered by hardware (scenario Figure 4). To compute the difference of instant of time of approximately $8\mu s$, it was used $T_{ASK}/2 = 100\mu s$. The trigger voltage levels in the two SAs were 1.4V, positive edge. The computed time can be due to different delays in response to trigger signals of the SAs and to different delays introduced by the external circuits to the SAs. Despite the lack of flat tops of the *section* waves, the measured value has better repeatability than in the experiment with triggers by software (see the tops between *sections*). The lack of flat tops is due to the fact that the computed difference of time instants is no longer far greater than the time precision of the SAs and for the time computed ($8\mu s$) and for the chosen ASK signal period ($100\mu s$) the relative error given by Equation 8 is far greater (about 45%).

This method gives the relative delay between the start of the measurements on multiple SAs but it does not give which triggers first. That can be found, in the case of the experiment with triggers by software, doing a delay (by software, a fraction of the delay computed) in the software trigger command in one of the SAs. If the medium delay increases then this is the SA more delayed. In other way it is the SA in advance. In case of the experiment with triggers by hardware, the delay can be introduced in one of the outputs of the CARD (B8) that makes the trigger in one SA. Other way is introducing a delay to the reaction to the hardware trigger in one SA through a software command to SA (from the computer) or manually programming in the SA.

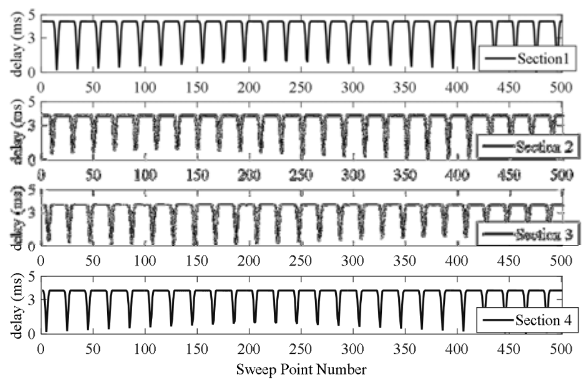

Figure 9 Computation Results of the difference between time instants of the start of the power measurements (in a sweep) between two SAs (Trigger by Software).

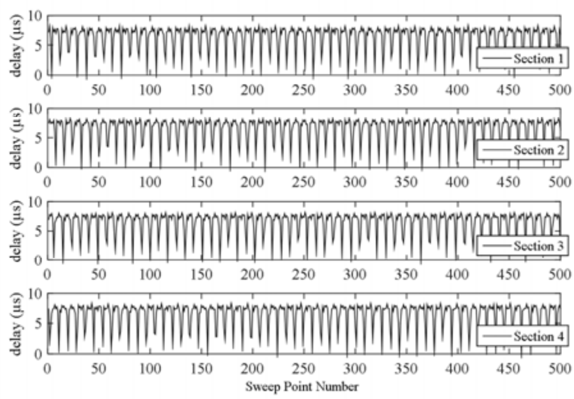

Figure 10 Computation Results of the difference between time instants of the start of the power measurements (in a sweep) between two SAs (Trigger by Hardware).

8. CONCLUSION

A new method to compute the time between the start of measurements in two or more SAs was presented. The method can have applications beyond the aim of the authors that it was to find out the better methods of trigger of SAs in order to achieve a better synchronism between measurements for spectrum occupancy for cognitive radio. Other application, it is to measure delays in transmission lines and so it length.

In the case of the time computed is far greater to the time imprecisions of the instruments and in case of the time computed be approximately one fourth of the ASK signal period, the computed time precision shows better results than the theoretical error reports. Beyond the fact that the theoretical error is for the worst case, the discrepancy can also be explained by the fact that in determination of the time, exists an error cancellation effect or/and the SAs precision, to measure power, is better than the specifications.

CONFLICT OF INTEREST

None.

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