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LOW COST COMPONENTS RADIOMETER IMPLEMENTATION FOR HUMAN MICROWAVE ELECTROMAGNETIC FIELD EMISSION DETECTION

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Abstract—In this paper, we describe the realization of a low cost radiometer which can be used to detect and show the microwave electromagnetic field emitted from human body. The system uses components available in the consumer market: low cost LNB (Low Noise Block: low noise pre-amplifier, mixer and post-amplifiers) and a parabolic antenna for satellite TV. The base line stability problems of the system are removed using a detector in linear region and a digital integrator for correction of the base line. The PC resident software triggers an educational video on the origins of electromagnetic radiation when a person, entering in the antenna beam, is detected; in addition to this, it is possible to show an infrared image taken by a camera.

1. INTRODUCTION

In this paper, we provide a description of a radiometer designed to detect the human electromagnetic field emission in the microwave spectrum range. The system is placed in a show room, and the antenna beam intercepts the opposite wall. The base line of the radiometer is given by the wall temperature. The system detects the difference between the body and the wall.

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The antenna operates in near-field, so the system works more properly as a "thermal probe", but it works correctly anyway because the target usually intercepts the entire beam (Figure 1).

Figure 1. Antenna positioning.

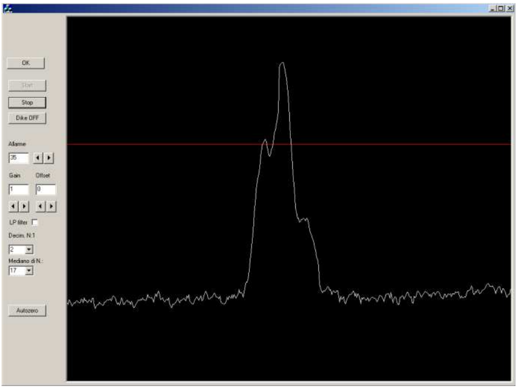

Figure 2. The detected signal shown on a PC monitor.

Figure 2 shows the detected signal when a person intercepts the antenna beam. The two small peaks are due to secondary lobes; the abnormal amplitude confirms that the antenna works in near field. When the signal passes the red line (a software adjustable threshold) an educational video starts.

The goal of the project is to evaluate the small difference in electromagnetic field emission between a human body (28–35°C) and the wall (18–28°C).

The general problems of radiometers are extensively analyzed in [1, 2]. The sensitivity of the different kinds of radiometers is analyzed in [3]. The main problem of every system is the thermal stability of its components.

In order to carry on this research, an LNB and a dish antenna for satellite TV have been used as a front-end. In our project, the main difficulties are due to:

- LNB gain and detection factor variations as a function of system temperature changes;
- environmental factors: during the day the temperature of the wall varies about 2–5 degrees up to 10–20 degrees according to climatic seasonal changes; this variation can exceed the difference in temperature between the human body and the wall.

After some experiments [4] using a Dike-like system configuration, we used a TPR (Total Power Radiometer) in "pseudo differential" configuration.

The project has been inserted within the Guglielmo Marconi Museum didactic area, with other experiments and explicative media.

2. POWER BUDGET EVALUATION

The total power P available at the input of the receiver is (Nyquist equation):

$$P = k\,(\eta T + T_R)\,B\ [\mathrm{W}] \tag{1}$$

T: temperature of the scene (human body or wall) seen by the antenna [°K], T_R: noise temperature of the system [°K], η: antenna efficiency (measured by producer), k: 1.38e-23 [J/°K] Boltzman constant, B: IF bandwidth [Hz]. The general configuration of a Total Power Radiometer to which we can refer to is the simple total power radiometer (Figure 3); the relationship between the temperature of the scene and the power available at the IF output is as follows:

$$P_n = kG_{tot}\,(\eta T + T_R)\,B\ [\mathrm{W}] \tag{2}$$

G_{tot} system total gain (linear).

The output of the diode detector is:

$$V_{diode} = C \cdot P_n \tag{3}$$

in quadratic region, or

$$V_{diode} = \sqrt{C \cdot P_n} \tag{4}$$

in linear region, where C is the detector sensitivity, usually in [mV/μW].

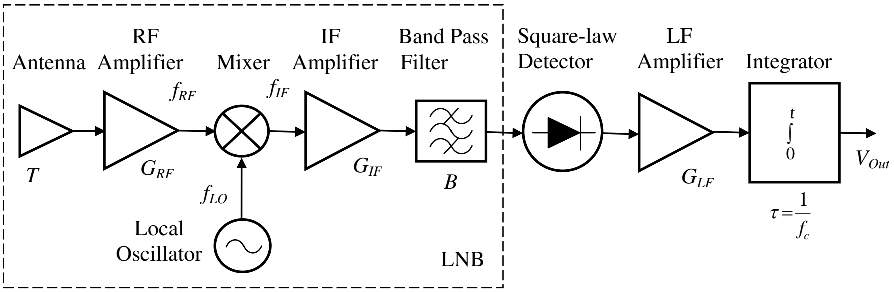

Figure 3. Block diagram of a typical Total Power Radiometer. The blocks grouped together by the dashed line are contained in a LNB.

In our system, at an Environment Temperature $T_{Env} = 300°\text{K}$ the Noise Temperature of the receiver T_R, corresponding to a LNB Noise Figure NF of 0.3 dB, is:

$$T_R = T_{Env}\left(10^{\frac{NF}{10}} - 1\right) = 21°\text{K} \tag{5}$$

therefore, considering the wall at a temperature $T_{Wall} = 300°\text{K}$, the System Temperature T_{Sys} is:

$$T_{Sys} = T_R + \eta T_{Wall} \cong 200°\text{K} \tag{6}$$

where η is the Electrical Efficiency of the antenna.

The minimum detectable temperature $\Delta T_{\min}$ (or Sensitivity) is given by:

$$\Delta T_{\min} = 2\frac{T_{Sys}}{\sqrt{B\frac{1}{f_c}}} = 0.049°\text{K} \tag{7}$$

where B is the Receiver Bandwidth (about 1 GHz) and f_c is the Cut-off Frequency of the post detection low pass filter (or integrator with time constant $\tau = 1/f_c$).

The system must detect a 10 degrees ΔT, which represents the difference between the temperature of the body intercepting the antenna beam and the temperature of the wall. The Sensitivity is much smaller than the above mentioned ΔT, therefore the system works.

Table 1. LNB and antenna technical characteristics, radiometer performance.

Parabolic mirror:	Gain	41 dB
	Efficiency — η:	60%
LNB (commercial satellite)	Radio Frequency Band — f_{RF}	11–12 GHz
	Intermediate Frequency — f_{IF}	1–2 GHz
	Gain — G_{RF}	60 dB
	Noise Figure — NF	0.3 dB
IF amplification (Line Amplifier)	Gain — G_{IF}	20 dB
	Noise Figure — NF	7 dB (typical)
Detector	Type	Schottky (positive)
	Sensitivity	0.8 V/mW (typical)
Radiometer performance	Receiver Noise Temperature — T_R	21°K
	System Temperature — T_{Sys}	200°K
	Post Detection Bandwidth — f_c	15 Hz
	Sensitivity — $\Delta T_{\min}$	0.049°K

Table 2. Power budget.

	Wall	Body
Temperature	$\approx 300\,°\text{K}$ (27°C)	310°K (37°C)
Received power	−85.57 dBm	−85.44 dBm
Power from LNB	−25.57 dBm	−25.44 dBm
Power from IF Ampl.	−5.57 dBm	−5.44 dBm

Table 3. Comparison between required post-detection gain in absence and in presence of a line amplifier between LNB and detector. In the first case, the detector operates only in the quadratic zone, in the second case it also operates in the linear region.

	Quadratic		Linear	
	Wall	Body	Wall	Body
P_{RF} [mW]	0.00249	0.00256	0.24889	0.25645
$V_{detector}$ [mV]	2.98662	3.0773	149.331	153.869
V_{diff} [mV]	0.09075		4.53760	
Gain	41321 (92 dB)		826 (58 dB)	

Table 1 summarizes the system parameters. Table 2 summarizes the target and wall available noise power variations at line amplifier output.

3. THE BENEFIT TO USE THE POWER DETECTOR IN THE LINEAR REGION

Since the equipment should provide only a qualitative indication, a direct proportionality relationship between noise power input and detector output voltage is not required, so it is possible to operate within the linear region [5].

The best solution is to increase the power level of the intermediate frequency signal supplied to the detector input via a line amplifier between LNB and detector, in order to reduce the Low Frequency gain. The change of power corresponding to observing system $\Delta T = 10°\text{K}$ is approximately 0.2 mW or 0.13 dB, using a line amplifier with 20 dB gain.

In the Table 3, we summarize the voltage and the DC gain to obtain a 3 Vpp on the ADC (Analog to Digital Converter).

We assumed a detection coefficient equal to 1.2 and an ADC

Table 4. Wall line-base excursions for a typical wall thermic variation.

Base line variation (wall temperature)		
Seasonal wall [°C]	18	35
Wall temperature [°K]	291	308
Output power LNB [dBm]	−26.17	−25.93
Output power line amplifier [dBm]	−6.17	−5.93
Power on detector [mW]	0.24	0.26
Detector Voltage [mV]	289.70	306.63

full scale voltage equal to 3.5 V. It is possible to verify (Table 4) the advantage of using a detector in the linear region by calculating the base-line excursions for a typical wall thermic variation (18–35°C).

4. HARDWARE DESCRIPTION

Since the system is designed to detect when a person enters the antenna beam, by subtracting from the instantaneous value of the signal the long period integrated system noise (the receiver noise plus the ambient thermal noise received by the antenna), the receiver will be sensitive only to fast changes. This solution is digitally achievable using a microcontroller [7, 8] and does not require special components but only the choice of the integration time.

The minimum temperature detectable by the system depends also on the filter time constant. The filter, built using operational amplifiers, combined with the off-set circuit, provides a DC amplification which permits an output signal variability range between 0 and 5 V, corresponding to the range of the ADC.

The first PWM (Pulse Width Modulation[†]) is set during turn-on, to bring the signal within the ADC window, while the second PWM is the true-integrator canceller for slow varying time factor (hourly).

The overall gain of the amplification chain is 1331. With a 0.289 V pre-offset the seasonal variation oh the last stage output is 1.60 V.

The DC voltage detector output is filtered by a fifth order low-pass filter, with Cut-off Frequency of about 15 Hz. This value was chosen taking into account the necessity of an output signal fast rise during body transit, but at the same time, the necessity of containing the possible signal short-term fluctuations.

† A PWM signal consists in a fixed period square wave with variable ratio of "0 and 1" (dut, duty cycle). The low pass filtered output is a D.C. voltage equal $V_{dc} = V_{one} * \text{dut}$.

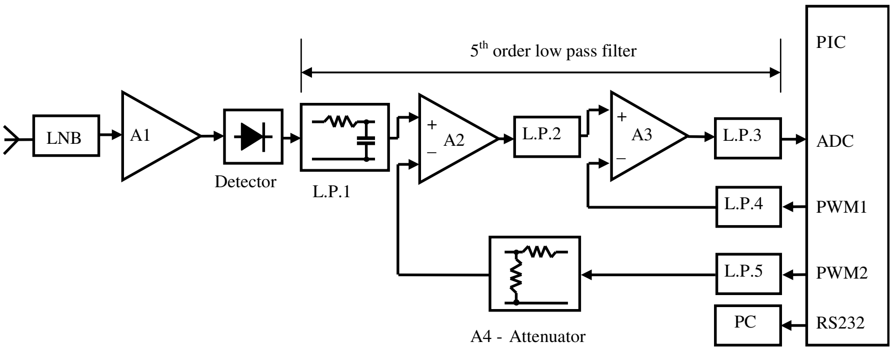

Figure 4. System block diagram. A1 Line Amplifier, L.P. Low Pass filter.

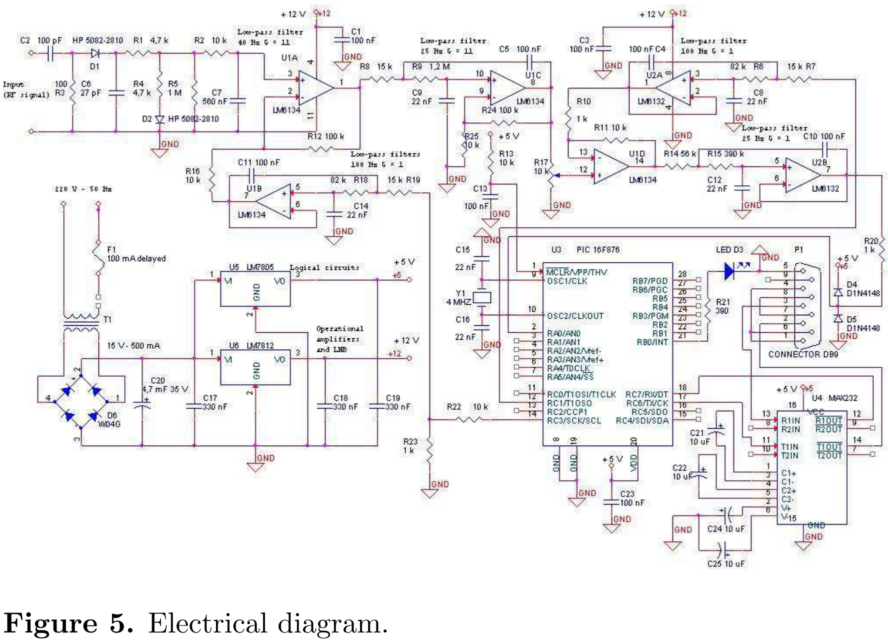

Figure 5. Electrical diagram.

The amplification chain contains only one true stage of filtering, but 3 more points are available for filter insertion (Figure 4, Figure 5), making it possible to bring the filter order to 5 (Table 5).

The resulting Low Pass filter Cut-off Frequency (f_c) is 15 Hz.

Table 5. Gain and filters characteristics.

	1	2	3	4	5
Amplifier	20 dB	11	11	0,1	
L.P. — Low Pass filter	$f_c = 40$ Hz 1st order gain = 1	$f_c = 25$ Hz 2nd order gain = 11	$f_c = 25$ Hz 2nd order gain = 1	$f_c = 100$ Hz 2nd order gain = 1	$f_c = 100$ Hz 2nd order gain = 1

5. SOFTWARE DESCRIPTION

The microcontroller provides to signal acquisition and ADC conversion for the subsequent transmission to a PC at 19200 baud (or bit per second). The transmission of one sample, using a RS232 interface [6], requires:

$1\ \mathrm{CHAR}->1\ \mathrm{start}+8\ \mathrm{ASCII}+1\ \mathrm{stop}=10\ \mathrm{bits}$ (number of bits)

Message (4 decimal digits)$-><\mathrm{sync}><4*\mathrm{CHAR}<\mathrm{CR}><\mathrm{LF}>$ $=7$ CHARS (number of chars)

The maximum frequency sampling is:

$$F_{sample\,\max} = \frac{baud\_rate}{n\_bit \cdot message} = \frac{19200}{10 \cdot 7} = 274\ \mathrm{Hz} \qquad (8)$$

The sample rate should be:

$$5 \cdot f_c = 75\,\mathrm{Hz} \qquad (9)$$

Nyquist frequency is 137 Hz, the 75 Hz frequency has been chosen in order to minimize disturbances at 50 and 25 Hz due to the aliasing.

The drifts active cancellation is made using a simple software integrator, according to the flow chart presented in Figure 6.

The integration time is defined as the time necessary to saturate the integrator output with an error equal to a sampling quantum. As a consequence, a time equal to N samples should be awaited before making a correction:

$$N = \frac{T_i \cdot F_{sample}}{n\_levels}\ [\mathrm{sec}] \qquad (10)$$

where: N number of sampling, n_levels 1024 per 10 bit ADC, F_{sample} signal sampling frequency, T_i integration time.

A variable is increased or decreased at every conversion, depending on whether the input signal is higher or lower in comparison with the zero-line. The PMW1 correction of one bit is taken at the N-th sample run with a proper sign.

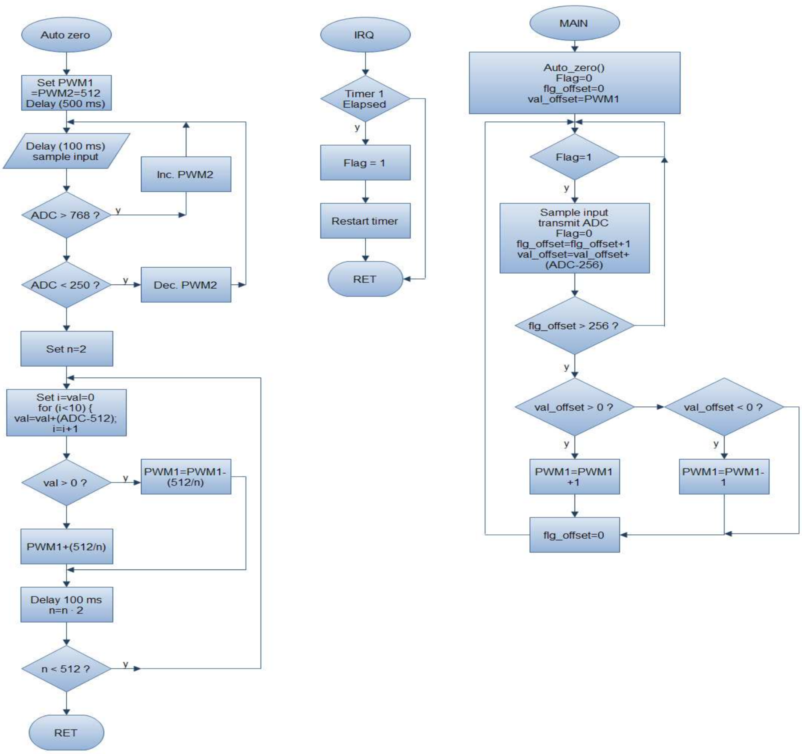

Figure 6. Autozero and integrator flow chart.

Occasionally an adjustment of the main correction is required: a second counter verifies that the saturation does not persist for more than few minutes, after this time a system reset is forced, to adapt to the new environment temperature conditions.

6. CONCLUSION

Devices, such as the one described in this paper may be useful in order to let general public become friendly with subjects involving electromagnetic fields; an issue that requires a specific preparation to be understood.

The cost of the system components, including the antenna is around 150 euros. As a consequence, didactic use in schools and museums is possible.

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