Experimental Study on Chaotic Synchronisation With Non-ideal Transmission Channel

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ABSTRACT : In this paper some new experimental results about synchronisation of chaotic circuits coupled by a non-ideal transmission channel are reported. In particular, the case of two Chua's oscillators, realised by State Controlled CNNs, and synchronised by using the inverse system approach has been considered. Two different studies have been carried out. In the first one, the effects of coupling the two systems by using a coaxial cable have been investigated by simulation. In the second one, the effects of adding noise and disturbances to the coupling signal in a real experimental set-up have been considered.

1. Introduction

Significant attention has been recently paid to the topic of the synchronisation of non-linear chaotic circuits especially because of their potential application in secure and spread spectrum communication systems [1-3]. Although experimental confirmations of the effectiveness of these techniques have been carried out, apart from a few cases [4-5], in these studies an ideal coupling between transmitter and receiver has been always considered [1-3]. In order to evaluate the effectiveness of such tecniques for practical purposes, there is a need of studies on the effects of noises, disturbances and non-idealities of the channel used to couple the transmitter to the receiver.

In the following the terms master, transmitter, encoder will be used interchangeably, analogously for the terms slave, receiver, and decoder.

In this paper some new results on this topic are presented. In particular two different cases have been considered. In the first part of the paper the effects of coupling the transmitter and the receiver by using a commercial coaxial cable have been investigated. Particular attention has been paid to the reconstruction of the chaotically coded signal by the decoder. In the second part, noise and disturbances have been added to the coupling signal in a real experimental set-up and their effects on the receiver have been evaluated. In this case, the "quality" of the synchronisation of the slave system when the noise, or a disturbance, is added onto the channel has been evaluated by using the cross correlation between the homologous variables of the master and slave system.

In the following, the case of the Chua's oscillator double-scroll dynamics realised by using State Controlled CNNs has been taken into consideration. In fact, apart from many significant theoretical implications [6], this approach has revealed that more robust circuit implementations can be realised [3]. The synchronisation method adopted has been the well known inverse system approach [2].

2. Circuit description

The circuit considered is composed by the four blocks shown in Fig. 1. Blocks B1 and B2 are two identical three-cell SC-CNN [3,6] realising the dynamic of the double-scroll. The corresponding circuit schematic is shown in Fig. 2. Block B3 (see Fig.3) is used to convert the voltage signal *V3* representing the message to be encrypted in the current *im*. This current is added to the node A (see Fig.1) and B1 responds with a chaotic modulated signal x_1 (the transmitted signal). Two buffers have been put between the channel input and the chaotic modulator B1 and between the channel output and the de-modulator B2 in order to avoid possible loads to the SC-CNN circuits.

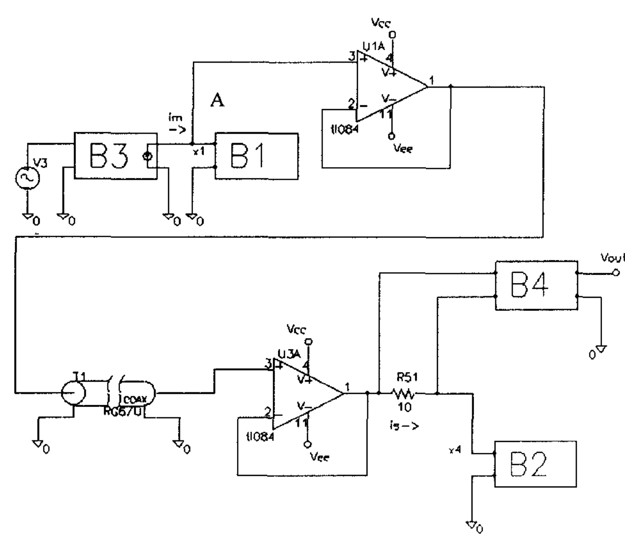

Figure 1 *Block diagram of the master-slave set-up.*

The synchronisation signal is imposed to the node corresponding to x_4 (the homologous of x_1 for the slave system B2) and B2 will respond drawing the current *is*. It is well-known [2] that iff B1 and B2 are synchronised then *is=im*. The current *is* will be transformed into the voltage *Vout* by the block B4 shown in Fig. 4.

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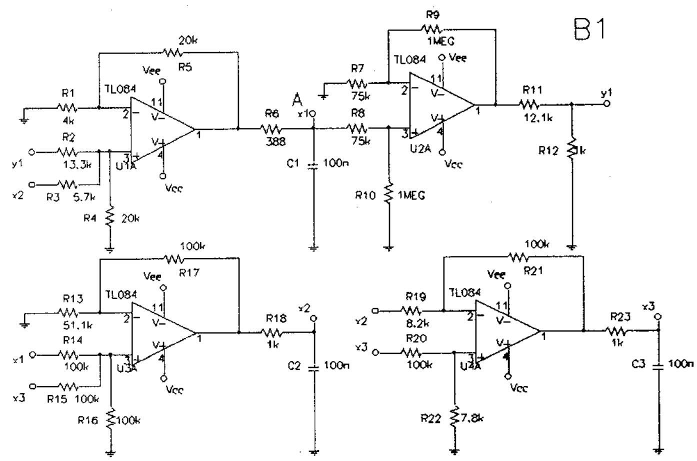


Figure 2 *State Controlled CNN realisation of the Chua's oscillator.*

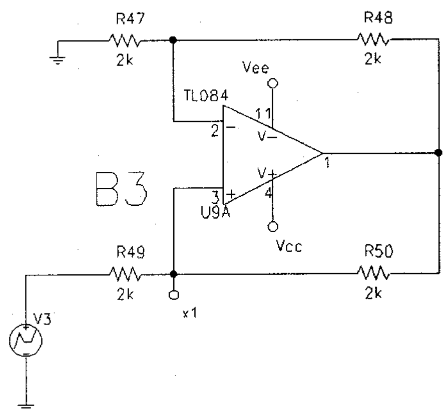


Figure 3 *Voltage to current converter realising the block B3.*

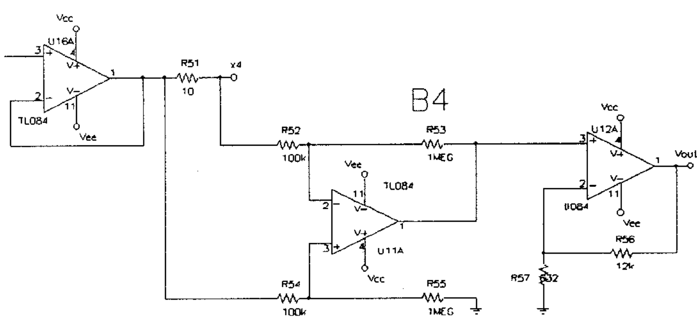


Figure 4 *Current sensing stage realising the block B4.*

3. Non-ideal channel effects

In this section the effects of coupling the transmitter and the receiver with a commercial coaxial cable are discussed. In particular the model RG6/U with characteristic impedance Z_0=75 Ω has been considered. Two different cases has been taken into account: in the first one the transmission channel has been adapted with its proper characteristic impedance, while in the second one the line is not adapted. The circuit referring to the latter case is the one shown in the above figures. Otherwise if the channel has to be adapted then a 75 Ω resistor must be inserted between the output of the buffer U1A and the input of the line T1 in Fig. 1; furthermore, another 75 Ω resistance must be inserted between the positive input of buffer U3A and the ground in the same figure. Moreover, due to the voltage divider effect at the input of the line T1, in this case, the buffer U3A must be replaced by a non-inverting stage with voltage gain G = 2.

Let us consider the ideal case in which the master and slave are directly coupled. Fig. 5 shows the sent and decoded messages overlapped. It is seen that apart from a brief transient, due to different initial conditions, the two waveforms are in a good agreement. This case will be considered as reference for the next discussion.

A triangular waveform is considered (as message) instead of a sinusoidal one because it is well known [1-4] that the behaviour of this system is dependent on the frequency and on the amplitude of the tone.

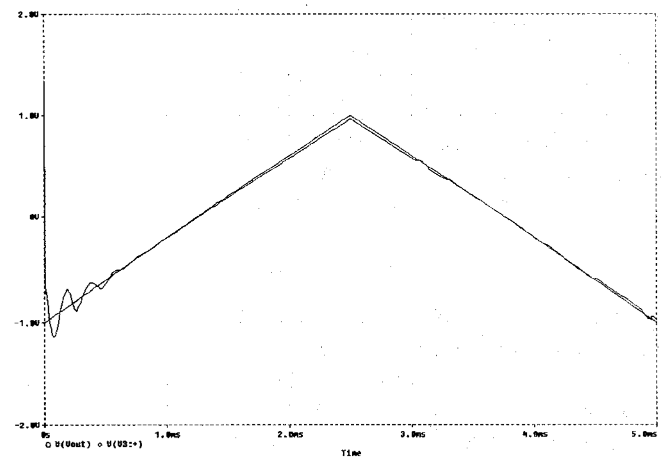


Figure 5 *Ideal case: transmitted and decode signal with direct coupled circuits.*

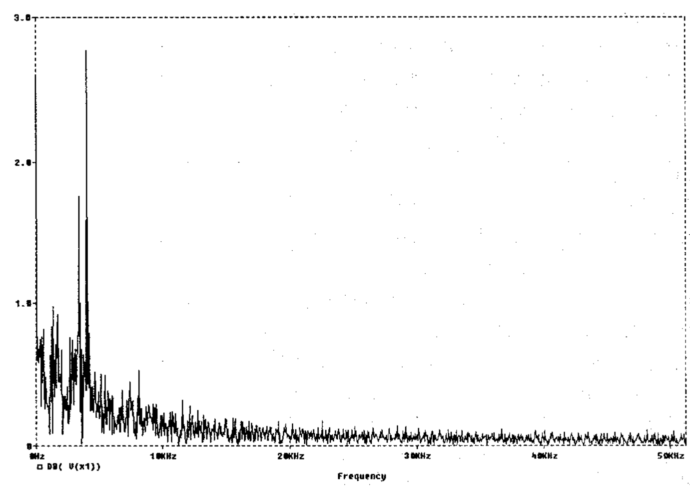
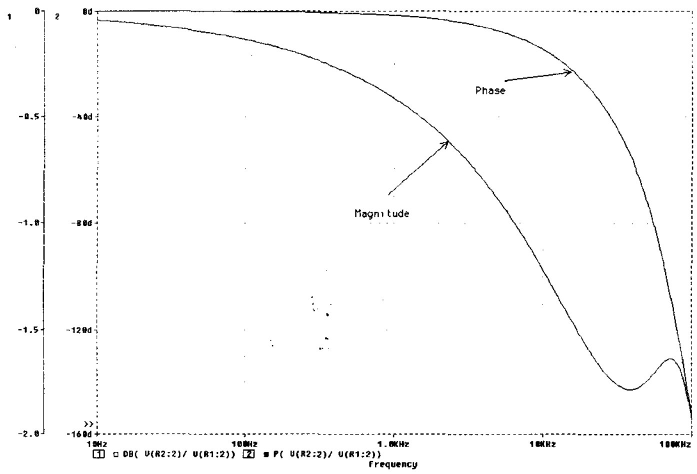


Figure 6 *Spectrum of the coupling signal x_1.*

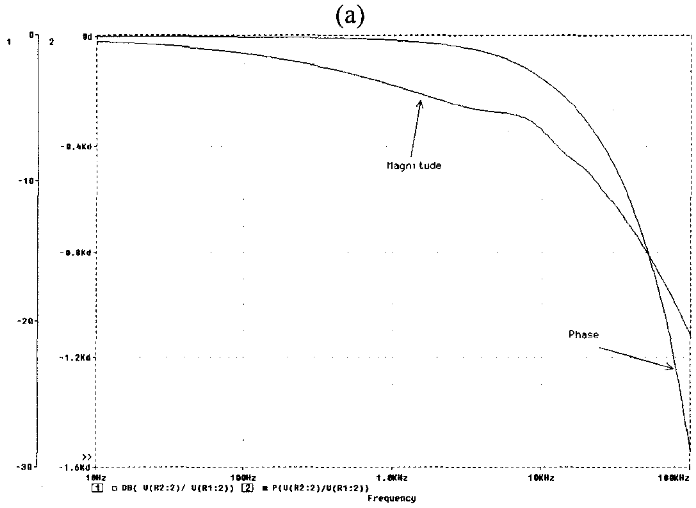
The spectrum of the synchronisation signal x_1, when the master is not forced by any message, is reported in Fig. 6.

It can be seen that the majority of the signal power is located in a band below 50KHz, therefore in the following it will be assumed that the signal is band-limited to this range.

The Bode plots of the transfer function of the adapted line for a 1Km long cable and 10Km long cable are reported in Fig. 7.



(a)



(b)

Figure 7 . *Bode plots of the transmission line for (a) 1 Km, (b) 10 Km.*

Let us consider the case of the adapted channel. In a first instance a 1 Km long line is considered. The corresponding transmitted and decoded wave-forms are reported in Fig. 8, while in Fig. 9 the case of a 10 Km line is depicted.

Of course, while in the first case there is still a good agreement among the two signals, in the case of the 10 Km cable the degradation due to the line is excessive.

If the line is not adapted then the corresponding wave-forms are the ones reported in Figs. 10-11. From them it follows that while for the 1 Km long cable the degradation is still acceptable (and comparable with the one of the adapted line), in the 10 Km case the distortion of the decoded message is greater than the one observed in the case of the adapted line.

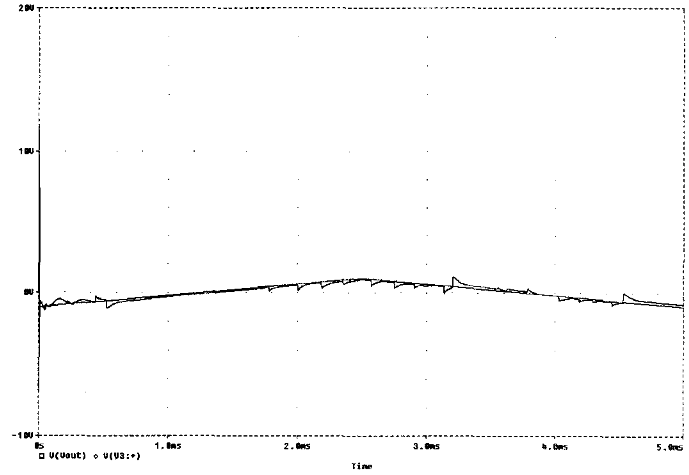


Figure 8 *Transmitted and decoded signal with a 1 Km long line.*

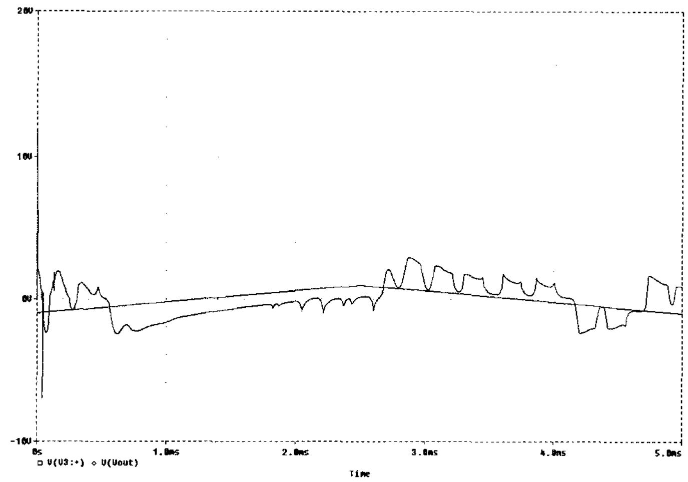


Figure 9 *Transmitted and decoded signal with a 10 Km long line.*

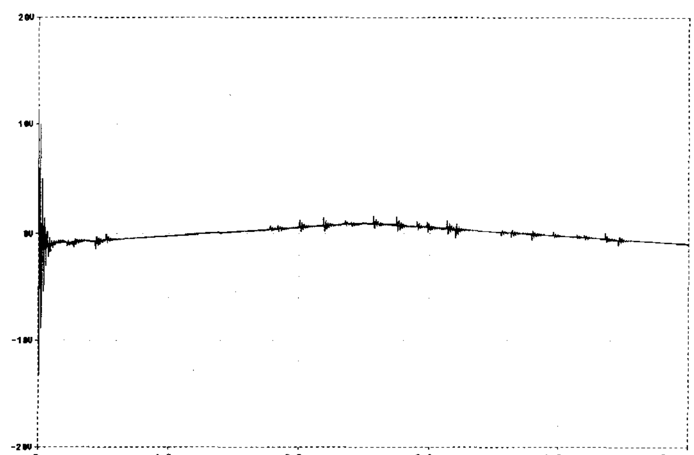


Figure 10 *Transmitted and decoded signal with a 1 Km long line for non adapted channel.*

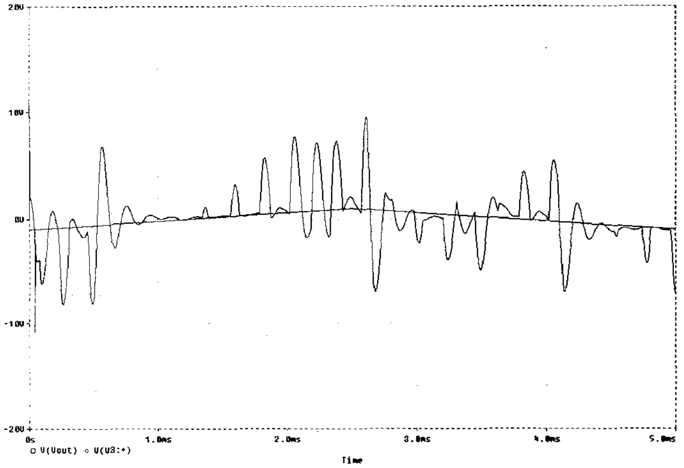


Figure 11 *Transmitted and decoded signal with a 10 Km long line for non adapted line.*

4. Effects of additive noise and disturbances onto the channel

In this second part the effects of additive noise and disturbances onto the synchronisation signal x_1 with respect to the "quality" of the synchronisation has been considered. Here an ideal coupling is assumed. The block diagram shown in Fig. 12 represents the experimental set-up. In particular the block B5 represents the noise generator embedded into the spectrum analyser used for the measurements (HP 35665A).

Three different situations have been taken into consideration. The first one deals with random noise, whose power spectrum for 1 Vpk (rms), is depicted in Fig.13.

In the second case a pink noise was added and its spectrum for 1 Vpk (rms), is depicted in Fig.14.

In the third case some sinusoidal disturbances with different frequency and amplitude have been added.

In order to evaluate the quality of the synchronisation the cross-correlation between the state variable x_2 (master) and x_5 (slave) has been considered:

$$R_{x2,x5}(\tau) = \lim_{T\to\infty} \frac{1}{T} \int_T x_2(t) x_5(t+\tau) dt \qquad (1)$$

Of course the cross-correlation decreases when the slave is badly synchronised. Moreover, in order to take into account of the increased energy supplied to the slave due to the noise and/or disturbance, the cross-correlation functions have been normalised with respect to their maximum values at the origin. So the normalised cross-correlation will be defined as:

$$R'_{x2,x5}(\tau) = {R_{x2,x5}(\tau)} \Big/ {R_{x2,x5}(0)} \qquad (2)$$

The results are summarised in the Table 1 ; in particular the energy $\varepsilon(R'_{x2,x5})$ of this normalised cross-correlation is reported for the various cases.

The reference values for the following comparisons are the ones reported in the first row of the table, in which an undisturbed transmission is considered. The following three rows consider the case of additive random noise with increasing power. As it is expected the energy of the normalised cross-correlation decrease as the noise power increases. Analogously, a similar decrement is observed in the case of pink noise (rows 5-6).

The last five rows illustrate the effect of sinusoidal disturbance. It is interesting to note that a tone around 1 KHz can be more harmful with respect to the synchronisation than a similar tone at a different frequency. This can be understood observing the spectrum of x_1; in fact, this is located around the frequency range in which the coupling signal has the majority of its power.

It is worth noting, from the table, as the synchronisation remains fairly insensible to the additive noise as claimed in [1-2].

Additive signal	Vpk (rms) / f (Hz)	$\varepsilon(R'_{x2,x5})$ (Joule)
No Noise	0	49.3387
Random Noise	2	43.4927
Random Noise	3	41.0844
Random Noise	5	32.5768
Pink noise	2	45.7839
Pink noise	3	39.6112
Sine	1/1K	31.8274
Sine	1/10K	36.0531
Sine	1/100	45.0874
Sine	2/1K	31.1263
Sine	1/560	34.1867

Table 1 *Measurement results.*

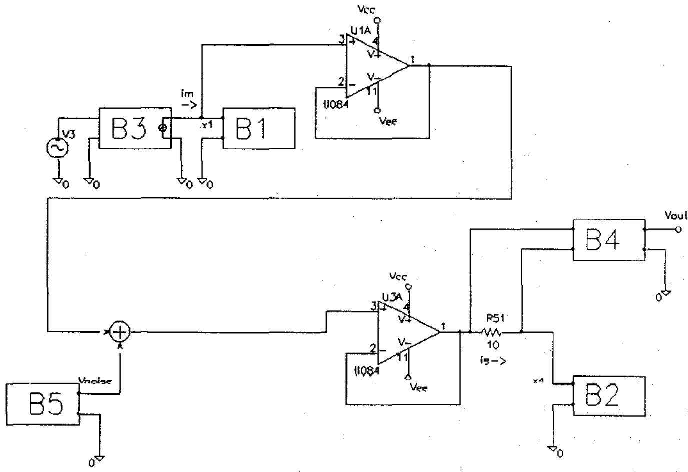


Figure 12 *Block scheme for the analysis of the effect of noise.*

5. Conclusion

In this paper an experimental analysis of the effects of non-ideal channel with respect to synchronisation of two chaotic circuits has been presented. Particular attention has been devoted to the use of coaxial line as a coupling media. Moreover the effects of additive noise and sinusoidal disturbances has been evaluated. From these last measures it follows up that a tone with suitable frequency can be disastrous. The collected data represents the starting point for the design of an optimal communication channel with respect to the length and the equalisation of the line. To this aim it can be easily argued that for short distances (less than some kilometers), as in the case of a local communication system (e.g. in a building), there could be no need of equalisation or even line impendance matching. However this is mandatory for longer communication channels.

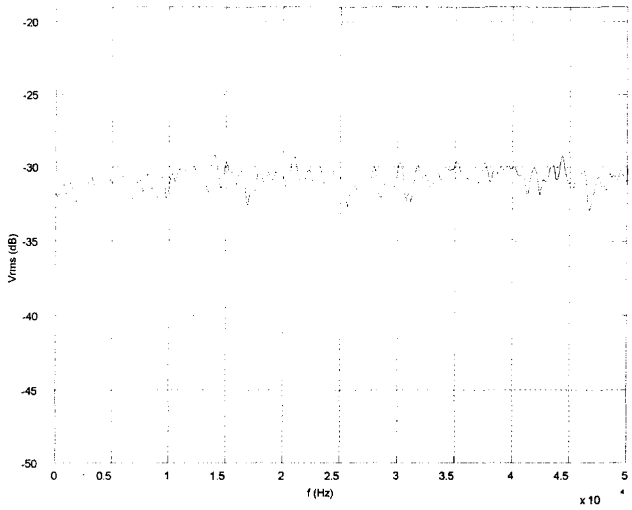


Figure 13 *Power spectrum of the random noise.*

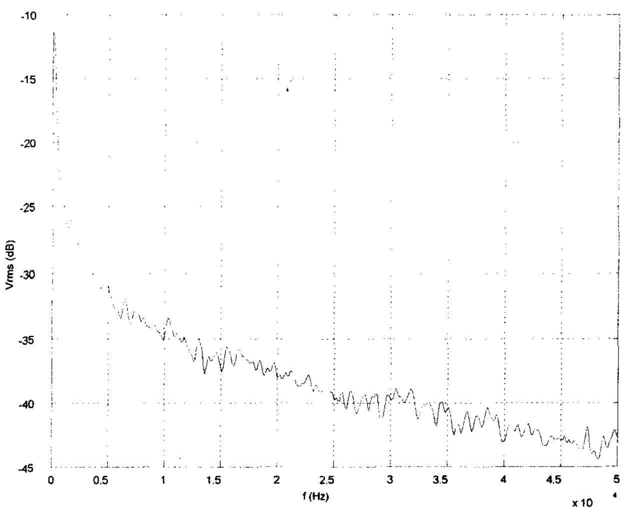


Figure 14 *Power spectrum of the pink noise.*

6. References

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