Communications with Mackey-Glass Electronic Circuits

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Mackey-Glass Model

- Models white blood cell production in the human body

- Described by delay differential equation:

\[
\dot{x} = \frac{ax_\tau}{1 + x_\tau^n} - bx
\]

- Decay term is proportional to the present cell count
- Nonlinear production term is a function of past cell count

Mackey-Glass Circuit

Current in circuit:

\[
C_o \dot{U} = \frac{U_{ND} \left( U_{T_d} \right)}{R_o} - \frac{U}{R_o}
\]
Nonlinearities:

\[ U_{ND}(x) = \frac{ax}{1 + x^n} \]
MG Model

MG Circuit

x(t)

PSD (dB)

Frequency (Hz)

-100 -80 -60 -40 -20 0

0 1 2 3 4 5 x 10^4

Numerical

Experimental

U(t)

PSD (dB)

Frequency (Hz)

-100 -80 -60 -40 -20 0

0 1 2 3 4 5 x 10^4

Numerical

Experimental
Synchronization

MG1 (closed loop)

MG2 (open loop)
Encoded Communication

![Diagram of encoded communication system]

- **Input**: $m(t)$
- **Block 1**: $T_d$, $R_o$, $C_o$ (ND)
- **Block 2**: $T_d$, $R_o$, $C_o$ (ND)
- **Output**: $m'(t)$
Power Spectra:

- $m(t)$
- TX
- RX
- TX-RX
- $m'(t)$
Time Series:

- $m(t)$
- $TX$
- $RX$
- $TX-RX$
- $m'(t)$
Radio Communication

\[ m(t) \xrightarrow{MG1} TX \xrightarrow{TCVR} RX \xrightarrow{MG2} \xrightarrow{LPF} m'(t) \]
Radio Communication

\[ f_{c1} = 390 \text{Hz} \]
\[ f_{c2} = 2050 \text{Hz} \]
Band-limited Coupling

MG1 - TX - LPF - TX' - MG2

RC Network
Fc = 365Hz

Cheby.
Fc = 324Hz
Band-limited Coupling

![Graph showing synchronization error vs. LPF cutoff frequency for Cheby. and RC filters with and without a filter.](image)
Conclusions

• Feedback circuits with time delay can generate chaos
• Precise synchronization of two such circuits can occur
• We can use chaotic waveforms to transmit and receive information
• Synchronization requires adequate coupling signal bandwidth
• High frequency, low power oscillations play a crucial role in synchronization