Bibliografia


Sergio Fugivara, Alison de O. Moraes, José C. J. de Almeida. *Aplicação da transformada de wavelets para compressão de dados de telemetria. CTA – Centro Técnico Aeroespacial*.


Anexos

I. Circuito esquemático do eletroencefalógrafo.

II. Circuito impresso do eletroencefalógrafo.

III. Circuito esquemático da eletrônica do manipulador.

IV. Circuito impresso da eletrônica do manipulador.

V. Código do microcontrolador da eletrônica do manipulador.

VI. *Datasheet* do amplificador instrumental INA114.
Anexo II

Face Superior
Face inferior
Anexo III
Anexo IV

Face superior
Face inferior
Anexo V

```c
#include <30f4013.h>
#DEVICE ADC=16
#FUSES XT_PLL8
#FUSES NOWDT
#use delay(clock=80000000)
#DEFINE DIR_1 PIN_F4
#DEFINE DIR_2 PIN_F5
#DEFINE DIR_3 PIN_F6
#DEFINE DIR_4 PIN_A11
#DEFINE DIR_5 PIN_C13
#DEFINE DIR_6 PIN_C14
#DEFINE I1A 0
#DEFINE I1B 1
#DEFINE I2A 2
#DEFINE I2B 4
#DEFINE I3A 5
#DEFINE I3B 8
#DEFINE POS1 9
#DEFINE POS2 10
#DEFINE POS3 11
#DEFINE POS4 12
#DEFINE eIi_lim 200000
#TYPE SIGNED
#include <stdlib.h>
#include <math.h>
#use rs232(UART1,baud=9600,parity=N,bits=8)

INT flag, xi, yi, zi, kii, kpi, kdi, kt_m2i, kti;

int16 elant=0, eil=0;

float q1=0, q2=0, q3=0, sum,sum2,p1_des, p2_des, p3_des, ep=0, epi[3], epd=0, e
pant[3], iki=0.005, ikp=0.1,kp=30.00,ki=0,kd=0,x,y,z,kt_m2,ang2,kt;

/****************************
// TRATAMENTO DOS DADOS SERIAIS //////////////////////////////////////////////////////
/****************************

#INT_RDA
```
void RDA_isr()
{
    xi = getc();
    yi = getc();
    zi = getc();
    kpi = getc();
    kii = getc();
    kdi = getc();
    kt_m2i = getc();
    kti = getc();
    flag = 1;
    x = xi;
    y = yi;
    z = zi;
    kp = (FLOAT) kpi / 100.00;
    ki = (FLOAT) kii / 1000.00;
    kd = (FLOAT) kdi / 100.00;
    kt_m2 = (FLOAT) kt_m2i;
    kt = (FLOAT) kti / 100.00;
}

//*****************************************************************************
// LEITURA DAS POSIÇÕES /////////////////////////////////////////////////////
//*****************************************************************************
float read_pos(INT link)
{
    FLOAT pos;
    set_adc_channel (link);
    delay_us (10);
    pos = read_adc();
    RETURN pos;
}

//*****************************************************************************
// Cinemática INVERSA /////////////////////////////////////////////////////
//*****************************************************************************

void id()
{
    flag = 0;
sum = pwr (x, 2) + pwr (y, 2) + pwr (z, 2);
sum2 = pwr (x, 2) + pwr (y, 2);

IF (y == 0)
{
    y = 0.0001;
}

p1_des = atan (x / y);
p2_des = atan (z / (sqrt (sum2))) - acos ((sum - 47.00) / (sqrt (sum) * 46.00));
p3_des = acos (((pwr (x, 2) + pwr (y, 2) + pwr (z, 2)) - 1105.0) / 1104.0);
printf ("LINK1 = %f LINK2 = %f LINK3 = %f", p1_des, p2_des, p3_des);
delay_ms (10);
putc (13);
delay_ms (10);
p1_des = ((p1_des * 360 / 2 / 3.1415) * (65536 - 4183) / 360) + 35200.00;
p2_des = ((p2_des * 360 / 2 / 3.1415) * (65536 - 4183) / 360) + 32600.00;
p3_des = ((p3_des * 360 / 2 / 3.1415) * (65536 - 4183) / 360) + 25000;
printf ("LINK1 = %f LINK2 = %f LINK3 = %f", p1_des, p2_des, p3_des);
delay_ms (10);
putc (13);
delay_ms (10);
printf ("kp = %f ki = %f kd = %f", kp, ki, kd);
delay_ms (10);
putc (13);
delay_ms (10);
printf ("Cons. de Torque = %f kt_pos = %f", kt_m2, kt);
delay_ms (10);
putc (13);
delay_ms (10);
printf ("----------------------------------------------")
延迟 ms (10);
putc (13);

IF (p3_des > 65536)
{
    p3_des = p3_des - 65536;
}

IF (p2_des > 65536)
float POS_contr(INT16 channel, float p, float p_des)
{
    FLOAT V = 0, ep1 = 0, ep2 = 0;
    ep = p_des - p;

    IF (ep > 34000)
        ep = - (65536 - ep);

    IF (ep < (-34000))
        ep = (65536 + ep);
    epi[channel] = epi[channel] + ep;
    epd = epant[channel] - ep;

    IF (epi[channel] > 100000)
        epi[channel] = 100000;

    IF (epi[channel] < (-100000))
        epi[channel] = -100000;
    V = ep * kp + epi[channel] * ki + epd * kd;
    epant[channel] = ep;

    IF (V > 10000)
        V = 10000;

    IF (V < -10000)
        V = -10000;

    IF ( (ep < 100)&& (ep > -100) )
        V = 0;
    RETURN V;
}
float q_grav (FLOAT ang)
{
    FLOAT i_grav;
    ang = ( (ang - 32600.00) / (65536 - 4183)) * 2 * 3.1415;
    i_grav = cos (ang) * ((0.88 * 9.8 * 0.07) + (0.963 * 9.8 * 0.23)) * kt_m2;
    RETURN i_grav;
}

void motor(INT link, float power)
{
    INT16 duty = 0;
    INT pin = 0;

    IF (power >= 0)
    {
        duty = (INT16) power;

        SWITCH (link)
        {
            CASE 1:
                output_low (DIR_1);
                set_pwm_duty (1, duty);
                BREAK;

            CASE 2:
                output_low (DIR_2);
                set_pwm_duty (2, duty);
                BREAK;

            CASE 3:
                output_low (DIR_3);
                set_pwm_duty (3, duty);
                BREAK;
        }
    }
ELSE
{
    duty = (INT16) (10000 + power);

    SWITCH (link)
    {
        CASE 1:
            output_high (DIR_1);
            set_pwm_duty (1, duty);
            BREAK;

        CASE 2:
            output_high (DIR_2);
            set_pwm_duty (2, duty);
            BREAK;

        CASE 3:
            output_high (DIR_3);
            set_pwm_duty (3, duty);
            BREAK;
    }
}

//****************************************************************************
//****************************************************************************
////////////////////////////////// MAIN /////////////////////////////////////
//****************************************************************************
//****************************************************************************

void main()
{

    INT loop_PID_POS = 0;

    FLOAT q1_POS = 0, q2_POS = 0, q3_POS = 0, q1_grav = 0, q2_grav = 0,
    q3_grav = 0, q1_cur = 0, IA = 0, IB = 0;
    FLOAT p1 = 0, p2 = 0, p3 = 0;
setup_timer1 (TMR_INTERNAL|TMR_DIV_BY_8, 30000);
setup_timer2 (TMR_INTERNAL|TMR_DIV_BY_64, 10000);
setup_adc (ADC_CLOCK_INTERNAL);
setup_adc_ports (ALL_ANALOG);
enable_interrupts (INT_RDA);
enable_interrupts (INTR_GLOBAL);
setup_compare (1, COMPARE_PWM|COMPARE_TIMER2);
setup_compare (2, COMPARE_PWM|COMPARE_TIMER2);
setup_compare (3, COMPARE_PWM|COMPARE_TIMER2);
setup_compare (4, COMPARE_PWM|COMPARE_TIMER2);

output_low (DIR_1);
output_low (DIR_2);
output_low (DIR_3);
set_pwm_duty (1, 0);
set_pwm_duty (2, 0);
set_pwm_duty (3, 0);
p3_des = 23530.00;
p2_des = 32600.00;
p1_des = 35200.00;
delay_ms (2000);

//****************************************************************************
****
// LOOP PRINCIPAL ///////////////////////////////////////////////////////////////////////////////////////
****
//****************************************************************************

WHILE (true)
{
  IF (flag == 1)
  {
    id ();
    flag = 0;
  }

  IF (loop_PID_POS == 1)
  {
    p1 = read_pos (POS1);
    p2 = read_pos (POS2);
p3 = read_pos (POS3) ;
// printf (" % f % f %f\n", p1, p2, p3);
q1_POS = POS_contr (1, p1, p1_des) ;
q2_POS = POS_contr (2, p2, p2_des) ;
q3_POS = POS_contr (3, p3, p3_des) ;

loop_PID_POS = 0;
}

motor (1, q1_POS);
motor (2, q2_POS);
motor (3, q3_POS);
loop_PID_POS++;
}
**Precision INSTRUMENTATION AMPLIFIER**

**FEATURES**
- LOW OFFSET VOLTAGE: 50μV max
- LOW DRIFT: 0.25μV/°C max
- LOW INPUT BIAS CURRENT: 2nA max
- HIGH COMMON-MODE REJECTION: 115dB min
- INPUT OVER-VOLTAGE PROTECTION: ±30V
- WIDE SUPPLY RANGE: ±2.25 to ±18V
- LOW QUIESCENT CURRENT: 3mA max
- 8-PIN PLASTIC AND SOL-16

**DESCRIPTION**

The INA114 is a low cost, general purpose instrumentation amplifier offering excellent accuracy. Its versatile 3-op amp design and small size make it ideal for a wide range of applications.

A single external resistor sets any gain from 1 to 10,000. Internal input protection can withstand up to ±40V without damage.

The INA114 is laser trimmed for very low offset voltage (50μV), drift (0.25μV/°C) and high common-mode rejection (115dB at G = 1000). It operates with power supplies as low as ±2.25V, allowing use in battery operated and single 5V supply systems. Quiescent current is 3mA maximum.

The INA114 is available in 8-pin plastic and SOL-16 surface-mount packages. Both are specified for the −40°C to +85°C temperature range.
## SPECIFICATIONS

### ELECTRICAL

All $T_a = +25°C$, $V_{CC} = +15V$, $R_f = 2kΩ$, unless otherwise noted.

<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>CONDITIONS</th>
<th>MIN</th>
<th>TYP</th>
<th>MAX</th>
<th>MIN</th>
<th>TYP</th>
<th>MAX</th>
<th>MAX</th>
<th>125°C</th>
<th>MAX</th>
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<td>Offset Voltage, RTI</td>
<td>$T_a = +25°C$</td>
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<td>±10</td>
<td>50</td>
<td>100</td>
<td>±10</td>
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<td>100</td>
<td>±10</td>
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<tr>
<td>vs Temperature</td>
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<td>vs Power Supply</td>
<td>$V_{CC} = 12.5V$ to 18V</td>
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<td>Impedance, Differential</td>
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<td>Common-Mode Rejection</td>
<td>$G = 10000$</td>
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<td>$V_{IN} = 110V, \overline{R}_L = 1kΩ$</td>
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<td>$G = 1000$</td>
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<td>$G = 100000$</td>
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<td>f = 1kHz</td>
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<td>f = 100kHz</td>
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<tr>
<td>f = 1MHz</td>
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<td>Operating Voltage Range</td>
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<tr>
<td>Operating Temperature Range</td>
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</table>

**Note:** Specifications same as INA114BPBU.

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PIN CONFIGURATIONS

- **P Package**
  - Top View
  - VCC
  - VSS
  - 1
  - 2
  - 3
  - 4
  - VCC
  - VSS
  - 8
  - 7
  - 6
  - 5

- **U Package**
  - SOL-16 Surface-Mount
  - Top View
  - NC
  - R
  - NC
  - NC
  - NC
  - NC
  - NC

ELECTROSTATIC DISCHARGE SENSITIVITY

This integrated circuit can be damaged by ESD. Burr-Brown recommends that all integrated circuits be handled with appropriate precautions. Failure to observe proper handling and installation procedures can cause damage.

ESD damage can range from subtle performance degradation to complete device failure. Precision integrated circuits may be more susceptible to damage because very small parametric changes could cause the device not to meet its published specifications.

PACKAGE/ORDERING INFORMATION

<table>
<thead>
<tr>
<th>PRODUCT</th>
<th>PACKAGE</th>
<th>PACKAGE DRAWING NUMBER</th>
<th>TEMPERATURE RANGE</th>
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<tr>
<td>INA114AP</td>
<td>8-Pin Plast DIP</td>
<td>005</td>
<td>-40°C to +85°C</td>
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<tr>
<td>INA114BP</td>
<td>8-Pin Plast DIP</td>
<td>000</td>
<td>-40°C to +85°C</td>
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<tr>
<td>INA114AJ</td>
<td>SOL-16 Surface-Mount</td>
<td>211</td>
<td>-40°C to +85°C</td>
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<tr>
<td>INA114BU</td>
<td>SOL-16 Surface-Mount</td>
<td>211</td>
<td>-40°C to +85°C</td>
</tr>
</tbody>
</table>

NOTE: (1) For detailed drawing and dimension table, please see end of data sheet, or Appendix C of Burr-Brown IC Data Book.

ABSOLUTE MAXIMUM RATINGS

- **Supply Voltage**: ±15V
- **Input Voltage Range**: ±40V
- **Output Short-Circuit (to ground)**: Continuous
- **Operating Temperature**: -40°C to +125°C
- **Storage Temperature**: -40°C to +125°C
- **Junction Temperature**: +150°C
- **Lead Temperature (soldering, 10s)**: +300°C

NOTE: (1) Stresses above these ratings may cause permanent damage.
TYPICAL PERFORMANCE CURVES

At $T_a = +25^\circ\text{C}$, $V_{cc} = \pm 15\,$V, unless otherwise noted.
TYPICAL PERFORMANCE CURVES (CONT)

At $T_a = 25^\circ\text{C}$, $V_{CC} = 5\text{V}$, unless otherwise noted.

- SLEW RATE vs TEMPERATURE
- OUTPUT CURRENT LIMIT vs TEMPERATURE
- QUIESCENT CURRENT vs TEMPERATURE
- QUIESCENT CURRENT AND POWER DISSIPATION vs POWER SUPPLY VOLTAGE
- POSITIVE SIGNAL SWING vs TEMPERATURE ($R_o = 2k\Omega$)
- NEGATIVE SIGNAL SWING vs TEMPERATURE ($R_o = 2k\Omega$)
TYPICAL PERFORMANCE CURVES (CONT)

At $T_A = 25^\circ C$, $V_A = 3.3V$, unless otherwise noted.

LARGE SIGNAL RESPONSE, $G = 1$

SMALL SIGNAL RESPONSE, $G = 1$

LARGE SIGNAL RESPONSE, $G = 1000$

SMALL SIGNAL RESPONSE, $G = 1000$

INPUT-REFERRED NOISE, 0.1 to 10Hz

1 nV

0.1 nV/Hz

100 mV

100 mV

100 mV

100 mV

100 mV
APPLICATION INFORMATION

Figure 1 shows the basic connections required for operation of the INA114. Applications with noisy or high impedance power supplies may require decoupling capacitors close to the device pins as shown.

The output is referred to the output reference (Ref) terminal which is normally grounded. This must be a low-impedance connection to assure good common-mode rejection. A resistance of 5kΩ in series with the Ref pin will cause a typical device to degrade to approximately 80dB CMR (G = 1).

SETTING THE GAIN

Gain of the INA114 is set by connecting a single external resistor, \( R_G \).

\[ G = 1 + \frac{50 \text{ kΩ}}{R_G} \]  

(1)

Commonly used gains and resistor values are shown in Figure 1. The 50kΩ term in equation (1) comes from the sum of the two internal feedback resistors. These are on-chip metal film resistors which are laser trimmed to accurate absolute values. The accuracy and temperature coefficient of these resistors are included in the gain accuracy and drift specifications of the INA114.

The stability and temperature drift of the external gain setting resistor, \( R_G \), also affects gain. \( R_G \)'s contribution to gain accuracy and drift can be directly inferred from the gain equation (1). Low resistor values required for high gain can make wiring resistance important. Sockets add to the wiring resistance which will contribute additional gain error (possibly an unstable gain error) in gains of approximately 100 or greater.

NOISE PERFORMANCE

The INA114 provides very low noise in most applications. For differential source impedances less than 1kΩ, the INA103 may provide lower noise. For source impedances greater than 50kΩ, the INA111 FET-input instrumentation amplifier may provide lower noise.

Low frequency noise of the INA114 is approximately 0.4µVp-p measured from 0.1 to 10Hz. This is approximately one-tenth the noise of "low noise" chopper-stabilized amplifiers.

![Figure 1: Basic Connections.](image-url)
OFFSET TRIMMING

The INA114 is zero trimmed for very low offset voltage and drift. Most applications require no external offset adjustment. Figure 2 shows an optional circuit for trimming the output offset voltage. The voltage applied to Ref terminal is summed at the output. Low impedance must be maintained at this node to assure good common-mode rejection. This is achieved by buffering trim voltage with an op amp as shown.

FIGURE 2. Optional Trimming of Output Offset Voltage.

INPUT BIAS CURRENT RETURN PATH

The input impedance of the INA114 is extremely high—approximately $10^9$Ω. However, a path must be provided for the input bias current of both inputs. This input bias current is typically less than ±1nA (it can be either polarity due to cancellation circuitry). High input impedance means that this input bias current changes very little with varying input voltage.

Input circuitry must provide a path for this input bias current if the INA114 is to operate properly. Figure 3 shows various provisions for an input bias current path. Without a bias current return path, the inputs will float to a potential which exceeds the common-mode range of the INA114 and the input amplifiers will saturate. If the differential source resistance is low, bias current return path can be connected to one input (see thermocouple example in Figure 5). With higher source impedance, using two resistors provides a balanced input with possible advantages of lower input offset voltage due to bias current and better common-mode rejection.

INPUT COMMON-MODE RANGE

The linear common-mode range of the input op amps of the INA114 is approximately ±13.75V (or 1.25V from the power supplies). As the output voltage increases, however, the linear input range will be limited by the output voltage swing of the input amplifiers, $A_p$ and $A_n$. The common-mode range is related to the output voltage of the complete amplifiers—see performance curve “Input Common-Mode Range vs Output Voltage”.

A combination of common-mode and differential input signals can cause the output of $A_p$ or $A_n$ to saturate. Figure 4 shows the output voltage swing of $A_p$ and $A_n$ expressed in terms of a common-mode and differential input voltages. Output swing capability of these internal amplifiers is the same as the output amplifiers, $A_p$. For applications where input common-mode range must be maximized, limit the output voltage swing by connecting the INA114 in a lower gain (see performance curve “Input Common-Mode Voltage Range vs Output Voltage”). If necessary, add gain after the INA114 to increase the voltage swing.

Input overload often produces an output voltage that appears normal. For example, an input voltage of -20V on one input and +40V on the other input will obviously exceed the linear common-mode range of both input amplifiers. Since both input amplifiers are saturated to nearly the same output voltage limit, the difference voltage measured by the output amplifier will be near zero. The output of the INA114 will be near 0V even though both inputs are overloaded.

INPUT PROTECTION

The inputs of the INA114 are individually protected for voltages up to ±60V. For example, a condition of -40V on one input and +40V on the other input will not cause damage. Internal circuitry on each input provides low series impedance under normal signal conditions. To provide equivalent protection, series input resistors would contribute excessive noise. If the input is overloaded, the protection circuitry limits the input current to a safe value (approximately 1.5mA). The typical performance curve “Input Bias Current vs Common-Mode Input Voltage” shows this input
current limit behavior. The inputs are protected even if no power supply voltage is present.

**OUTPUT VOLTAGE SENSE (SOL-16 package only)**
The surface-mount version of the INA114 has a separate output sense feedback connection (pin 12). Pin 12 must be connected to the output terminal (pin 11) for proper operation. (This connection is made internally on the DIP version of the INA114.)

The output sense connection can be used to sense the output voltage directly at the load for best accuracy. Figure 5 shows how to drive a load through series interconnection resistance. Remotely located feedback paths may cause instability. This can be generally be eliminated with a high frequency feedback path through $C_2$. Heavy loads or long lines can be driven by connecting a buffer inside the feedback path (Figure 6).

**FIGURE 4. Voltage Swing of $A_1$ and $A_2$.**

**FIGURE 5. Remote Load and Ground Sensing.**

**FIGURE 6. Buffered Output for Heavy Loads.**

**FIGURE 7. Shield Driver Circuit.**

**INA114**
FIGURE 8. RTD Temperature Measurement Circuit.


<table>
<thead>
<tr>
<th>ISA TYPE</th>
<th>MATERIAL</th>
<th>COEFFICIENT ($\degree$C)</th>
<th>$R_z$ (100Ω)</th>
<th>$R_x$ (100Ω)</th>
</tr>
</thead>
<tbody>
<tr>
<td>E</td>
<td>Chromel</td>
<td>58.5</td>
<td>3.42kΩ</td>
<td>55.2kΩ</td>
</tr>
<tr>
<td>J</td>
<td>Iron</td>
<td>30.2</td>
<td>4.12kΩ</td>
<td>84.8kΩ</td>
</tr>
<tr>
<td>K</td>
<td>Chromel</td>
<td>35.4</td>
<td>5.23kΩ</td>
<td>88.9kΩ</td>
</tr>
<tr>
<td>T</td>
<td>Copper</td>
<td>38.0</td>
<td>5.48kΩ</td>
<td>84.5kΩ</td>
</tr>
</tbody>
</table>

NOTES: (1) α=$-2$ μV/$\degree$C at 200µA. (2) $R_x$ provides lower-scale burn-out indication.
FIGURE 10: ECG Amplifier With Right-Leg Drive.

FIGURE 11: Bridge Transducer Amplifier.

FIGURE 12: AC-Coupled Instrumentation Amplifier.

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