Hands-On: Using MSP430 Embedded Op Amps

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An outline of this session

- **Provides hands on experience of setting up the MSP430's built in op-amp modules**
- **Look at the construction of the op-amp module, and the topologies it can offer**
  - Inverting mode, non inverting mode etc
- **Experiment with the different op-amp topologies**
  - A software signal generator is provided, to simulate the amplifiers
  - PC oscilloscope program is provided to observe the output

Current devices with op-amps

- **FG43x**
  - Three op-amps
  - Rail-to-rail input capability
- **FG461x**
  - Three op-amps
  - Rail-to-rail input capability
- **F22x4**
  - Two op-amps

Key op-amp features

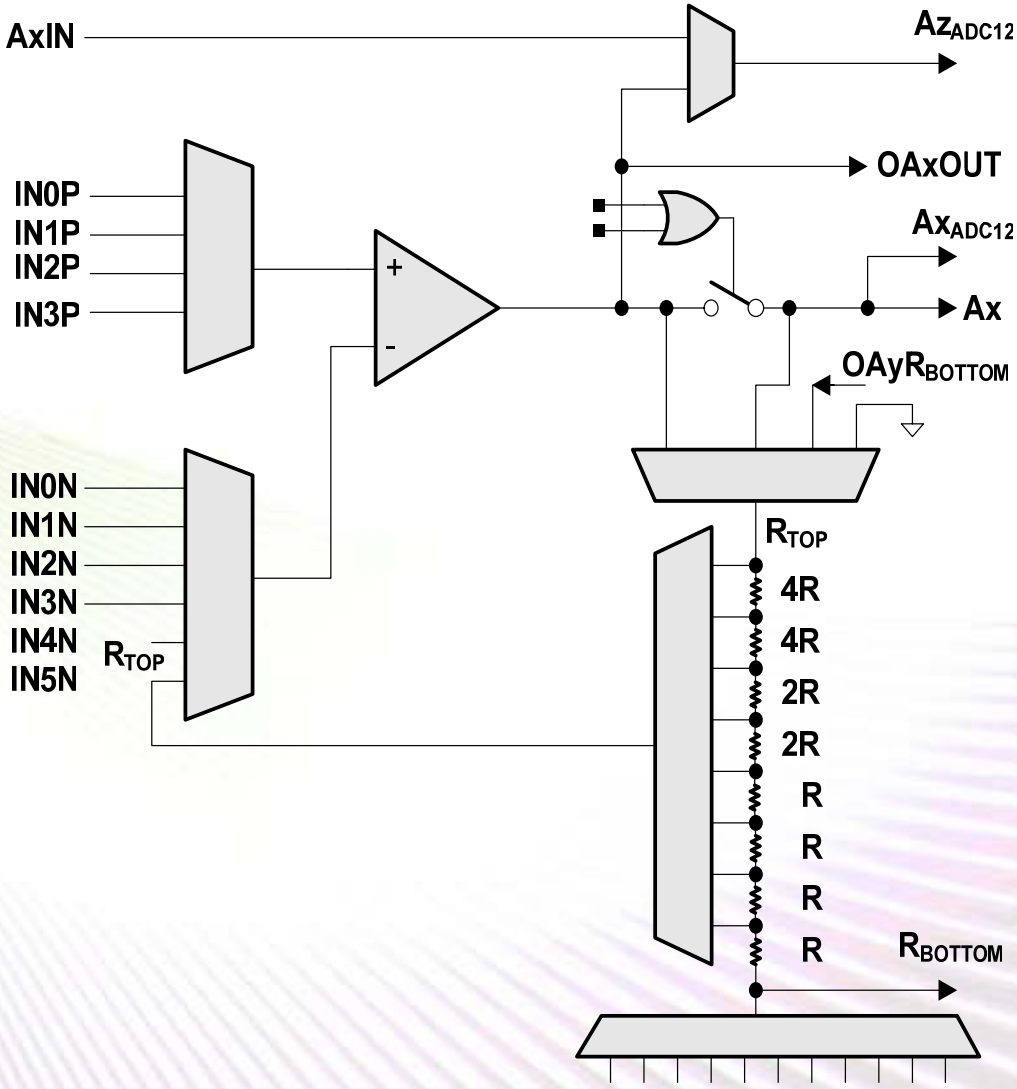
- **Three independent op-amps on-chip**
- **Selectable GBW product**
  - 500kHz, 1.4MHz, or 2.2MHz
  - The 500kHz GBW mode takes ~50uA
- **Class AB output for mA range drive**
- **Integrated charge pump for rail-to-rail input range & superior offset behavior (FG only)**
- **User-configurable feedback and interconnect**
  - Most designs need no external passive components
  - Internal connections to the ADC and DAC
  - Saves pins

Amplifier performance

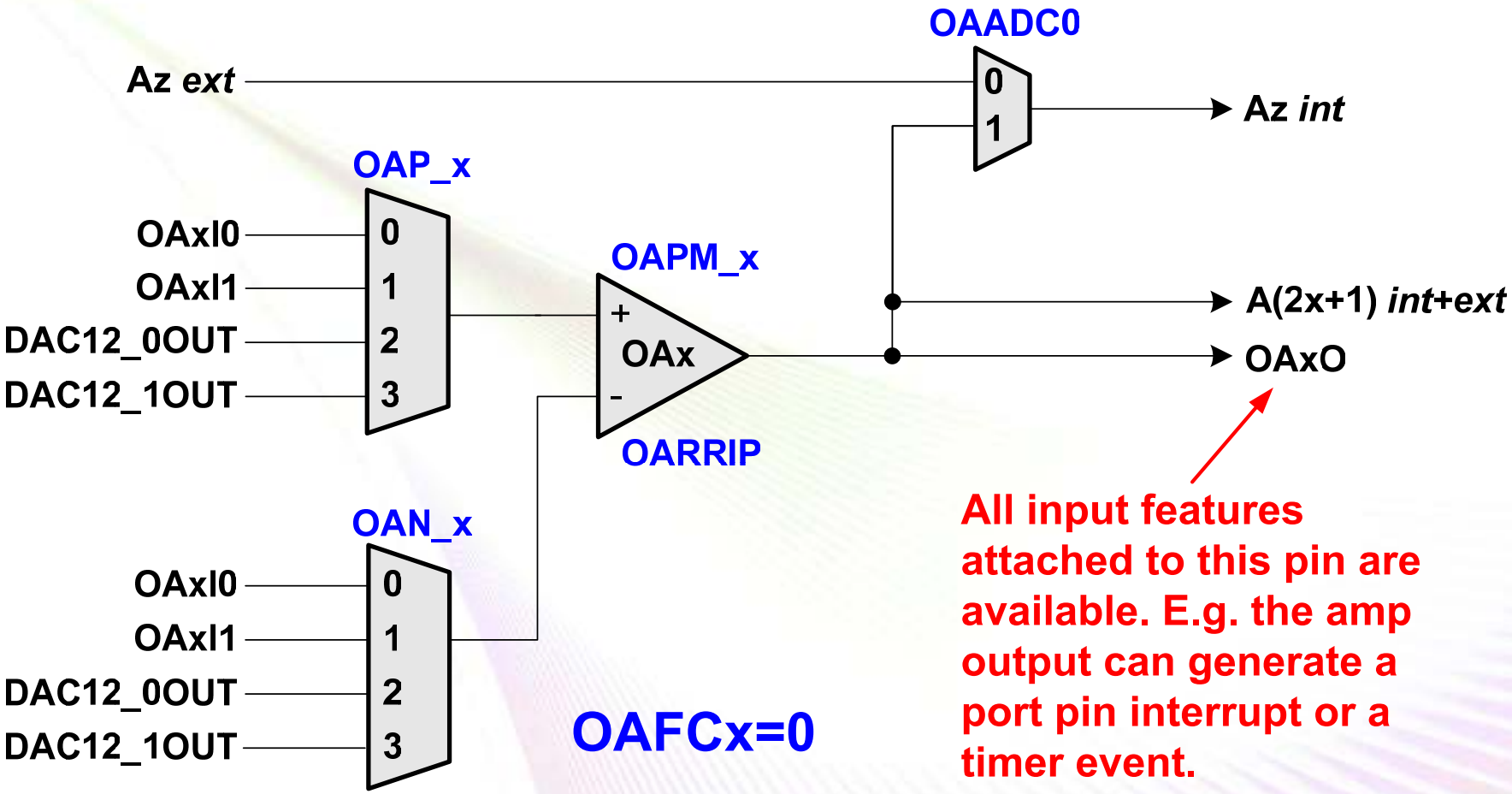
Amplifier Speed Setting	slow	medium	fast
Technology	0.35 um CMOS		
min. Supply Voltage	2.2 V		
DC gain	> 100 dB		
GBW @ 50 pF load	500 kHz	1.4 MHz	2.2 MHz
Phase margin @ 50 pF load	>= 60 °		
Slew Rate	0.5 V/us	1.2 V/us	2 V/us
Current consumption @ Charge Pump off	42 µA	110 µA	190 µA
Current consumption @ Charge Pump on	90 µA	200 µA	320 µA
CMRR	~ 80 dB		
PSRR	~ 80 dB		
Offset voltage	+/- 1 mV		
Input voltage noise (white noise) [nV/sqrt(Hz)]	60	35	28
Input voltage noise @ 1 kHz [nV/sqrt(Hz)]	75	55	45

Internal structure of each op-amp

- Flexible feedback network
- Internal R ladder
- Internally chainable
- Internal ADC and DAC connections

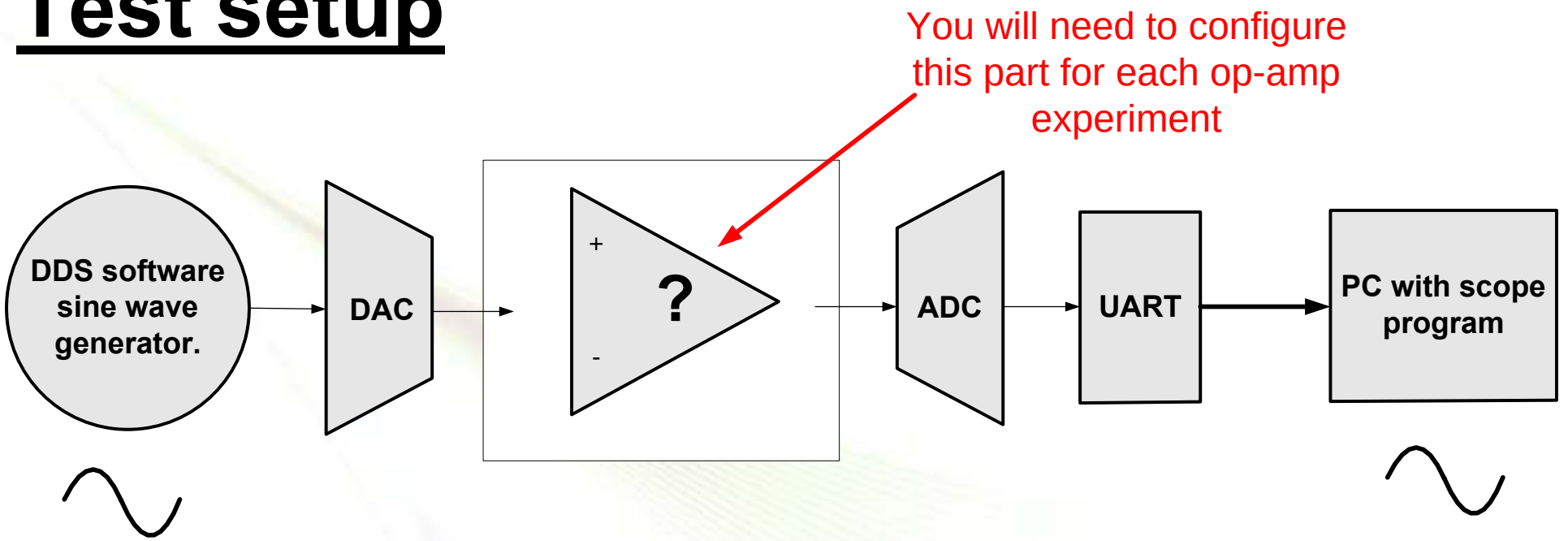


General purpose op-amp




```
OA0CTL1 |= OAFC_0;
OA0CTL0 |= OAP_1 | OAN_0 | OAPM_3;
```

Test setup



- **DDS sine wave generator software**
- **DAC12 > amplifier under test > ADC12**
- **Through isolated serial interface to PC**
- **Simple PC “scope” program to display output**

Let's get started…..

- **Find the project "op_amp_lab", open it, build it, and load it into the MSP430FG4619 on your board.**
- **Connect the board's RS232C port on your PC.**
- **Find the program "scope.exe", and run it on your PC.**
  - If you are using COM1, just click and run the program
  - If you are using another COM port (e.g. a USB→serial interface) find the port number, and use the Windows "run" option to run "scope <com port name>"

….Let's get started…..

- You should now have a sine wave on your PC, directly from the signal generator
- Comment out the following line with "//"

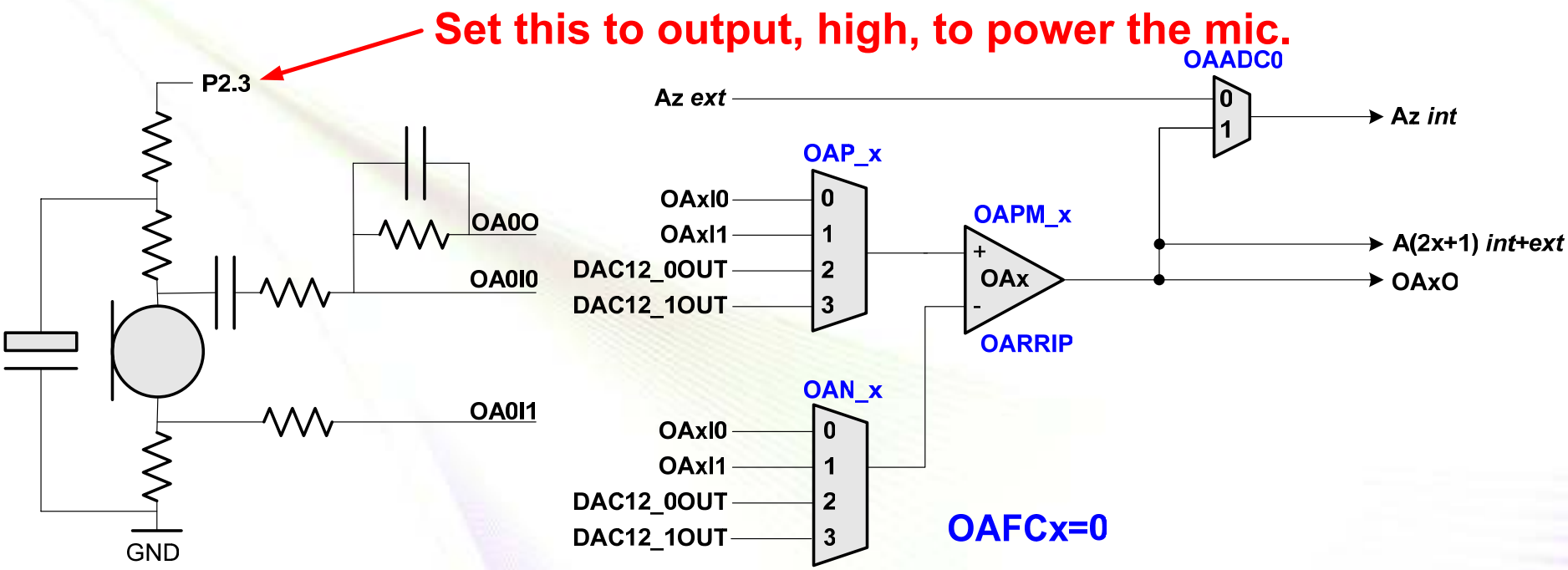
```
UCA0TXBUF = DAC12_0DAT >> 4;
```

- Uncomment the following line

```
//UCA0TXBUF = x;
```

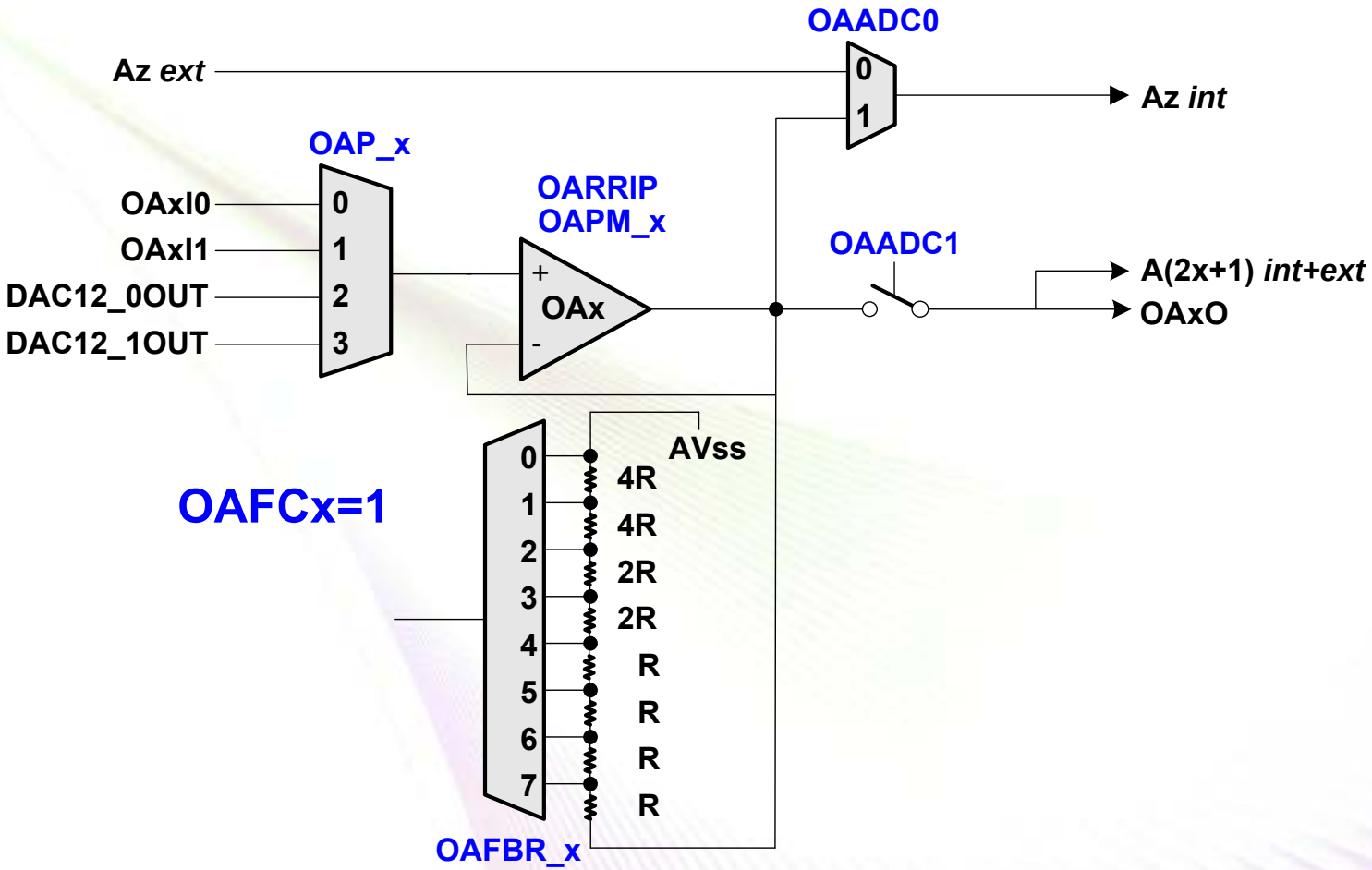
- You should now be seeing the output of the ADC12 – there's no signal right now.

Amplifying the microphone



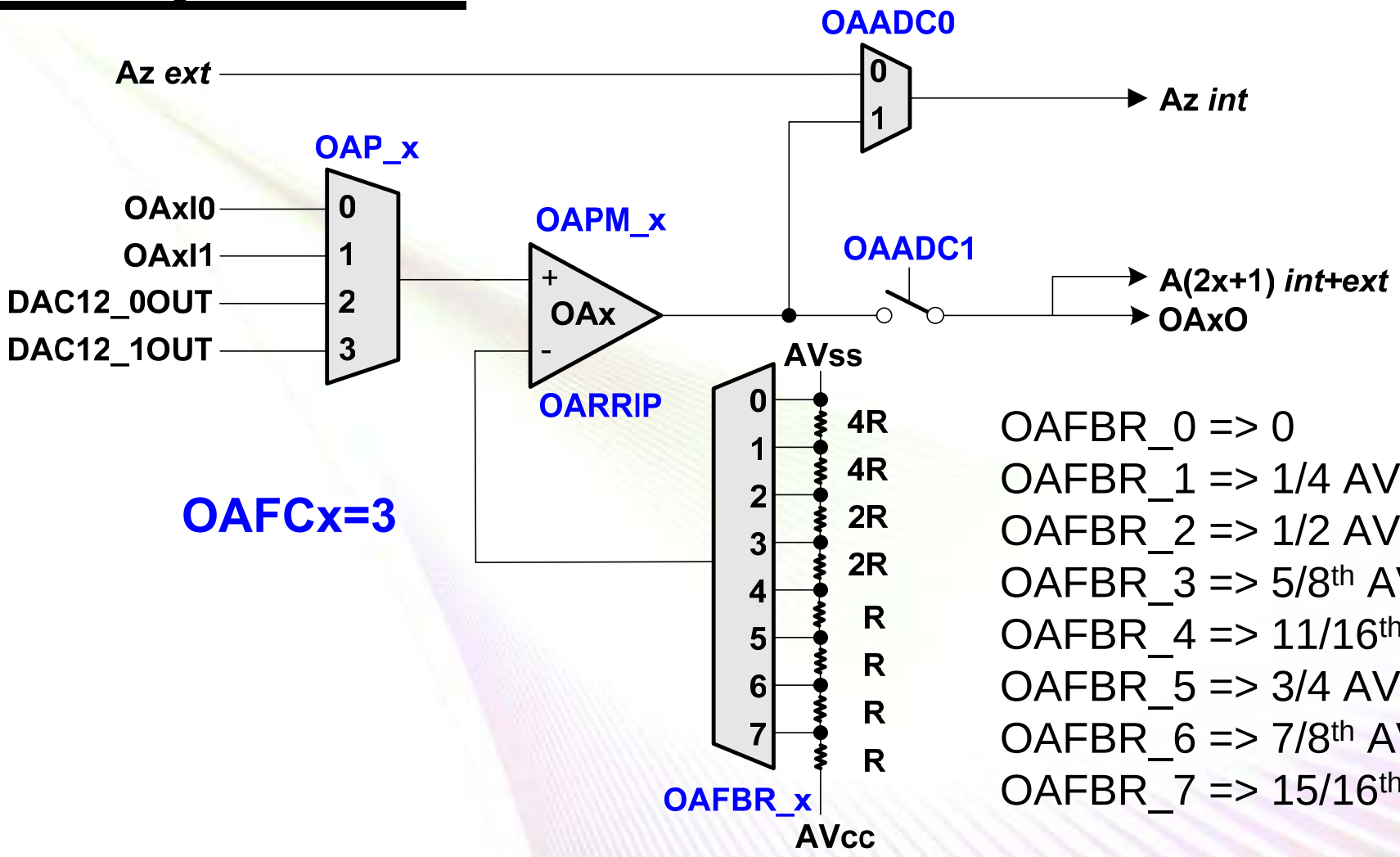

```
OA0CTL1 |= OAFC_0;
OA0CTL0 |= OAP_1 | OAN_0 | OAPM_3;
```

Unity gain, voltage follower




```
/* High performance buffering of DAC12_0 to the output */
OA0CTL1 |= OAFC_1;
OA0CTL0 |= OAP_2 | OAPM_3 | OAADC1;
```

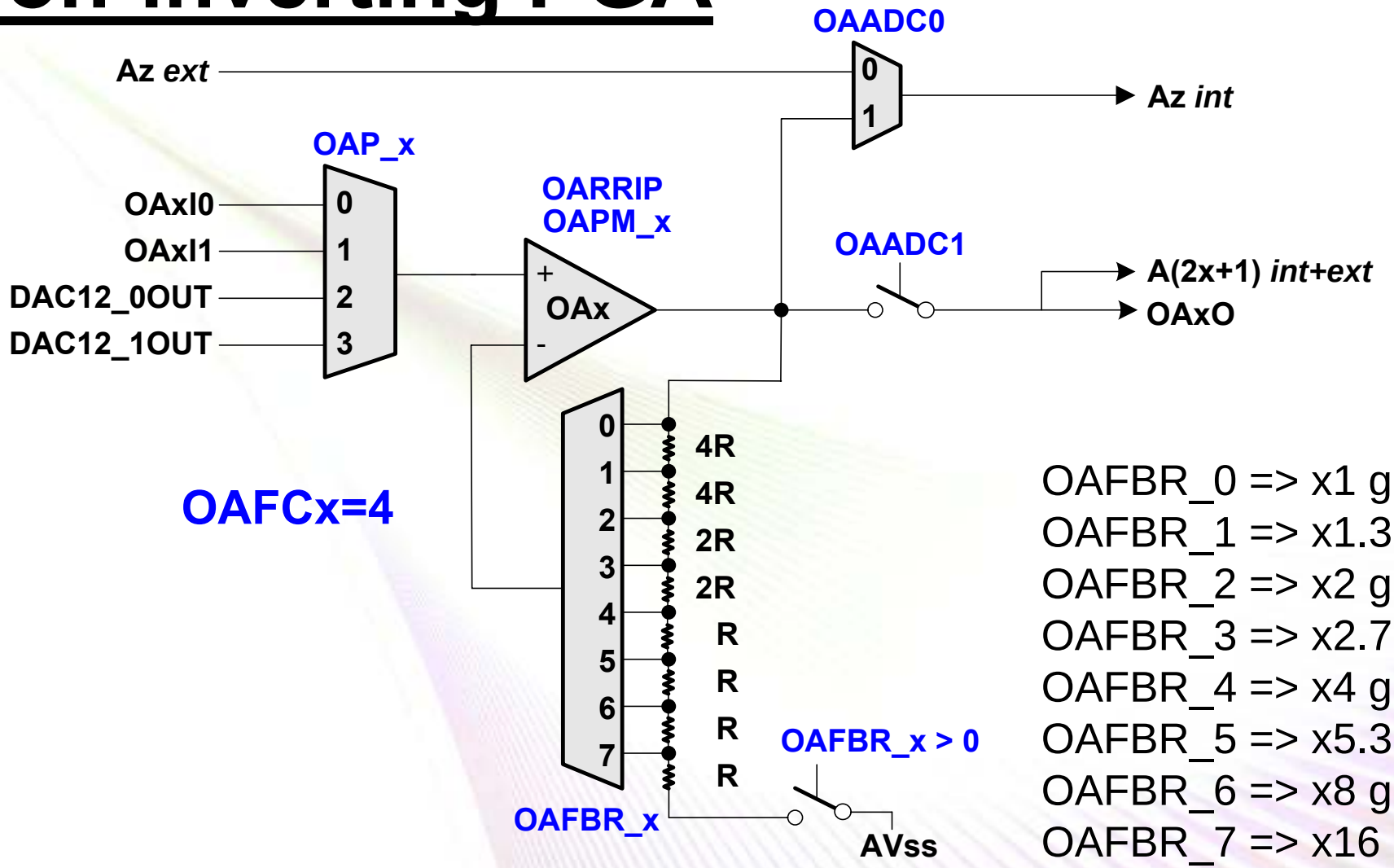
Comparator



OAFBR_0 => 0
OAFBR_1 => 1/4 AVcc
OAFBR_2 => 1/2 AVcc
OAFBR_3 => 5/8th AVcc
OAFBR_4 => 11/16th AVcc
OAFBR_5 => 3/4 AVcc
OAFBR_6 => 7/8th AVcc
OAFBR_7 => 15/16th AVcc

```
OA0CTL1 |= OAFC_3 | OAFBR_2;
OA0CTL0 |= OAP_2 | OAPM_3 | OAADC1;
```

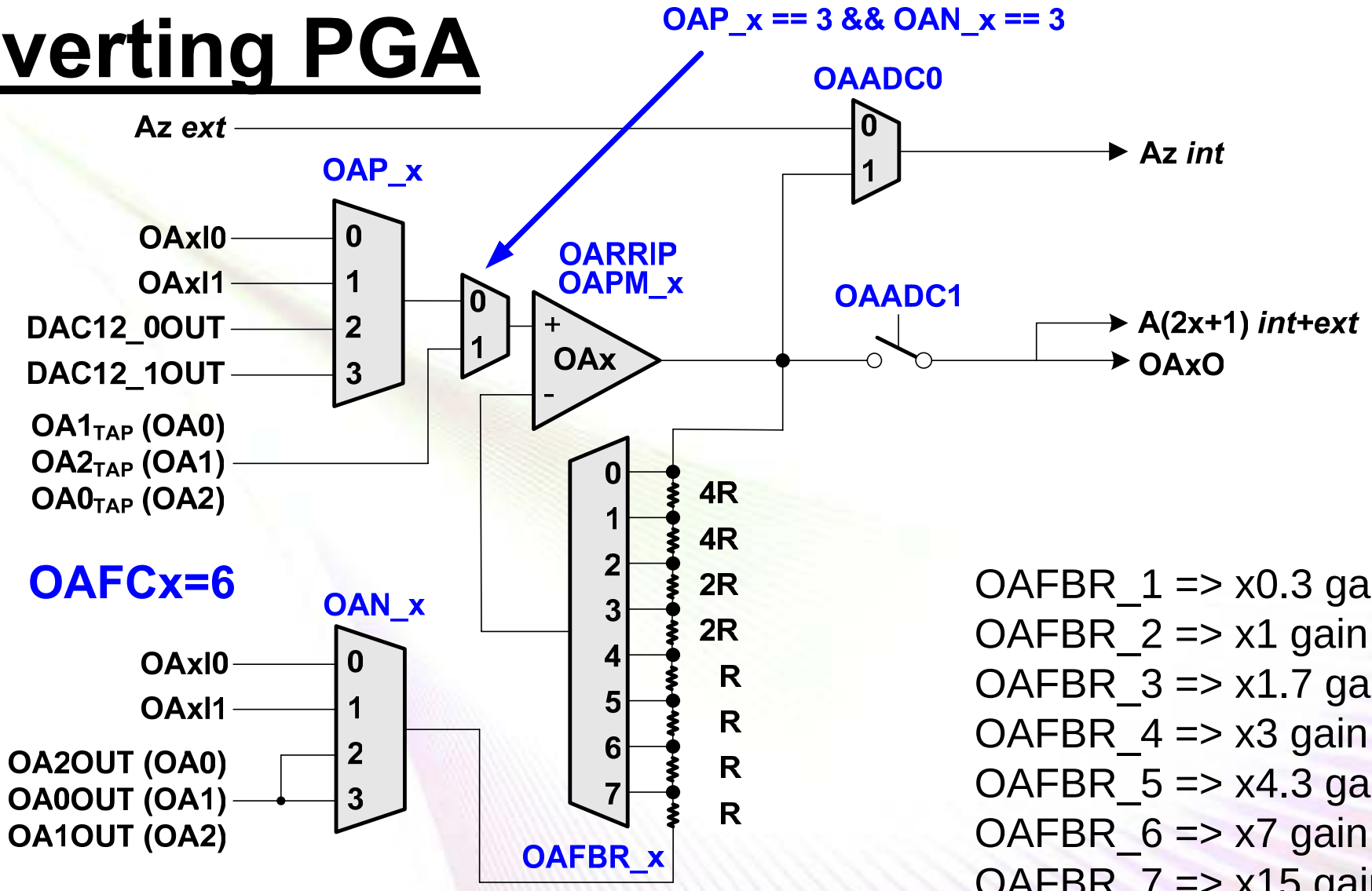
Non-inverting PGA



OAFBR_0 => x1 gain
OAFBR_1 => x1.3 gain
OAFBR_2 => x2 gain
OAFBR_3 => x2.7 gain
OAFBR_4 => x4 gain
OAFBR_5 => x5.3 gain
OAFBR_6 => x8 gain
OAFBR_7 => x16 gain

```
OA0CTL1 |= OAFC_4 | OAFBR_2;
OA0CTL0 |= OAP_2 | OAPM_3 | OAADC1;
```

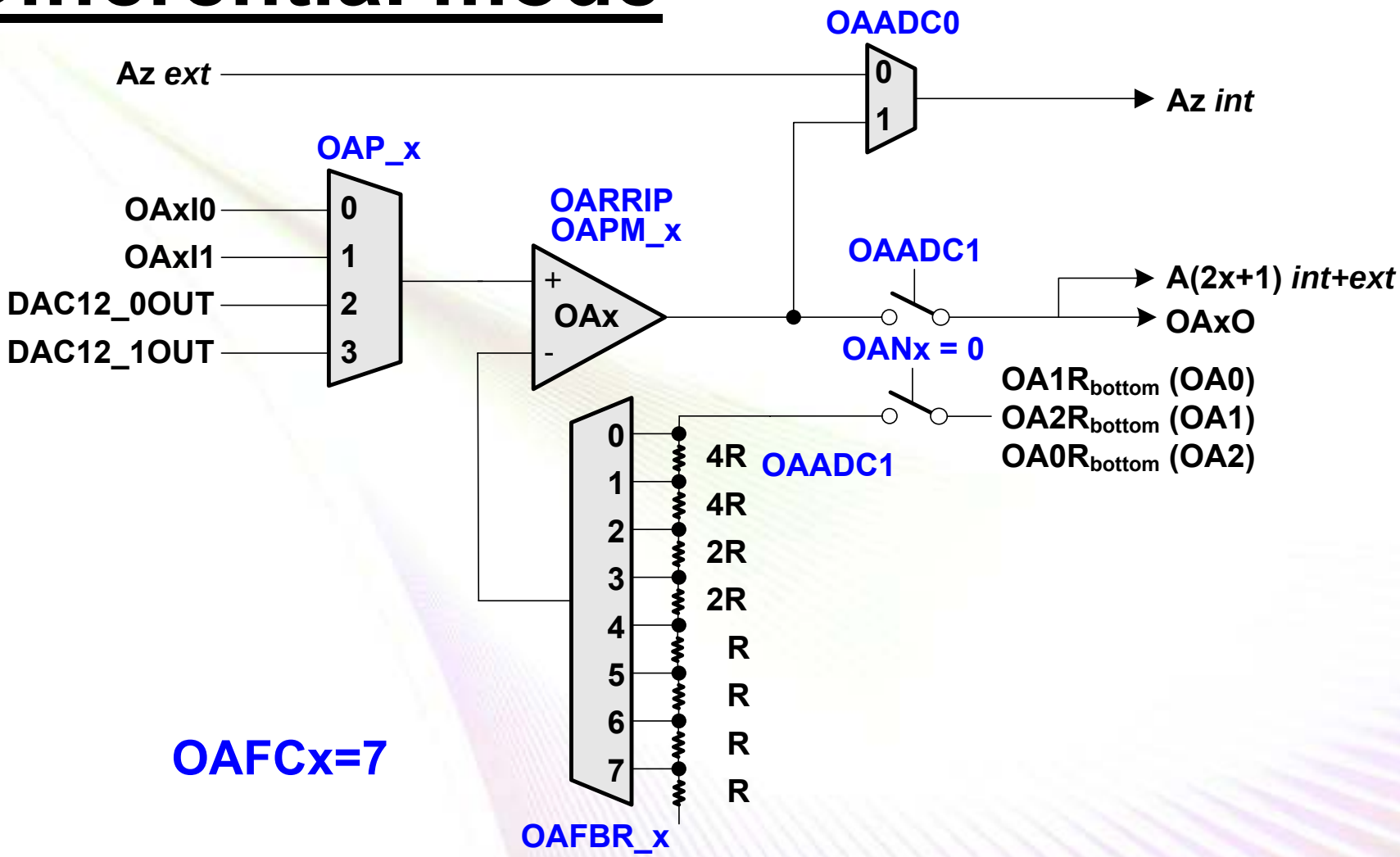
Inverting PGA



OAFBR_1 => x0.3 gain
OAFBR_2 => x1 gain
OAFBR_3 => x1.7 gain
OAFBR_4 => x3 gain
OAFBR_5 => x4.3 gain
OAFBR_6 => x7 gain
OAFBR_7 => x15 gain

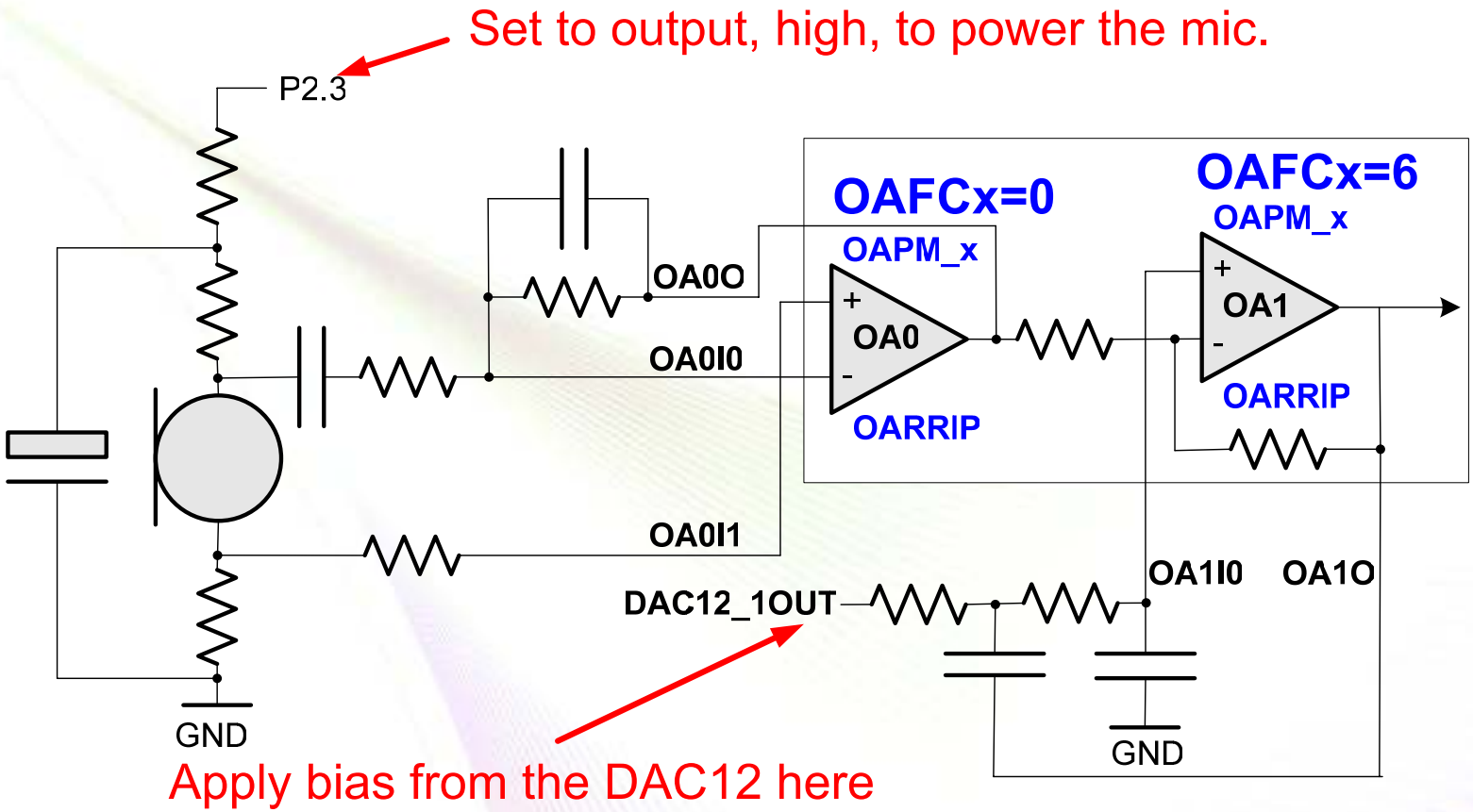
```
OA0CTL1 |= OAFC_6 | OAFBR_7;
OA0CTL0 |= OAP_3 | OAN_2 | OAPM_3 | OAADC1;
```

Differential mode



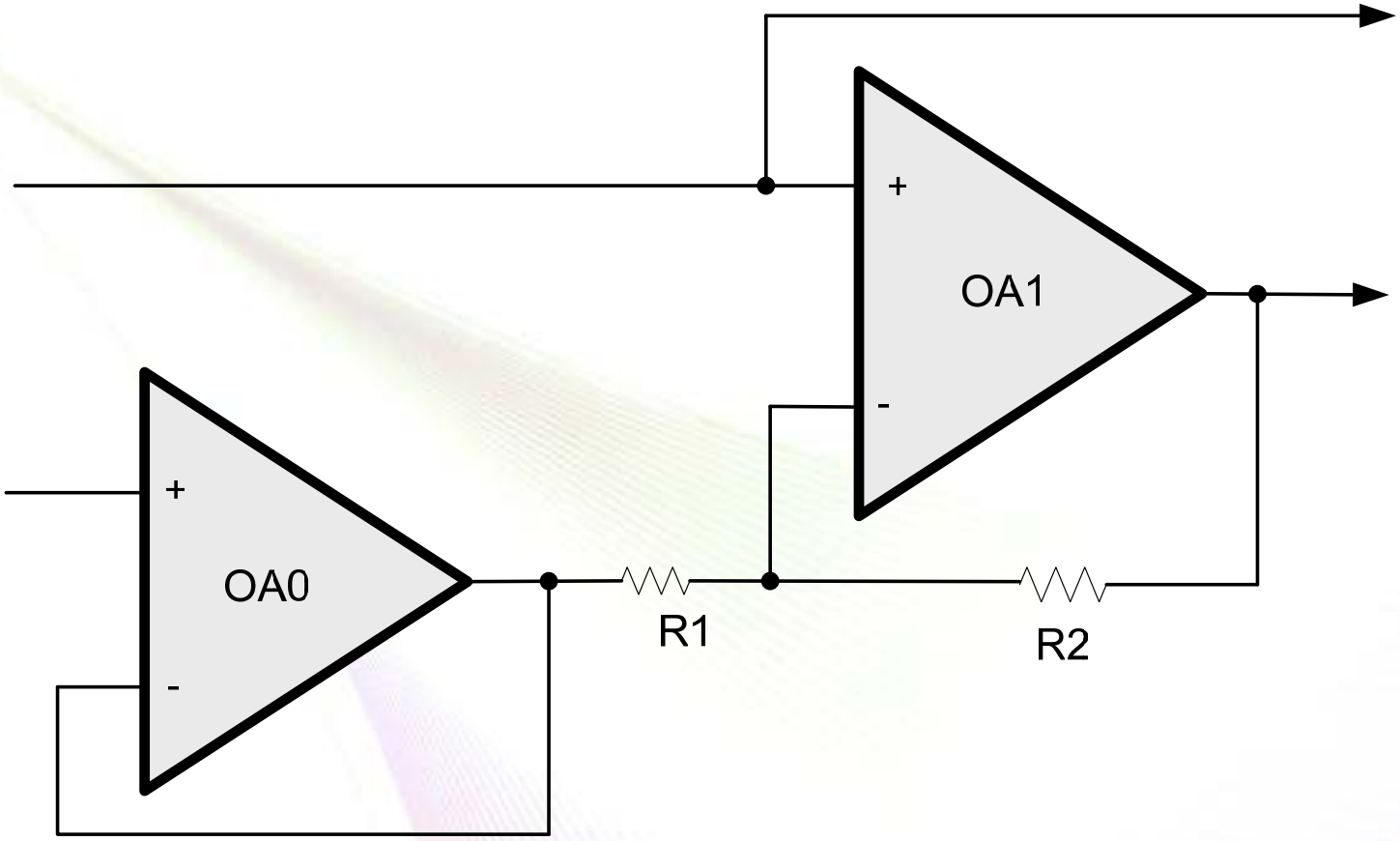

```
OA0CTL1 |= OAFC_7;
OA0CTL0 |= OAP_0 | OAN_0 | OAPM_3 | OAADC1;
```

2-amp microphone amplifier



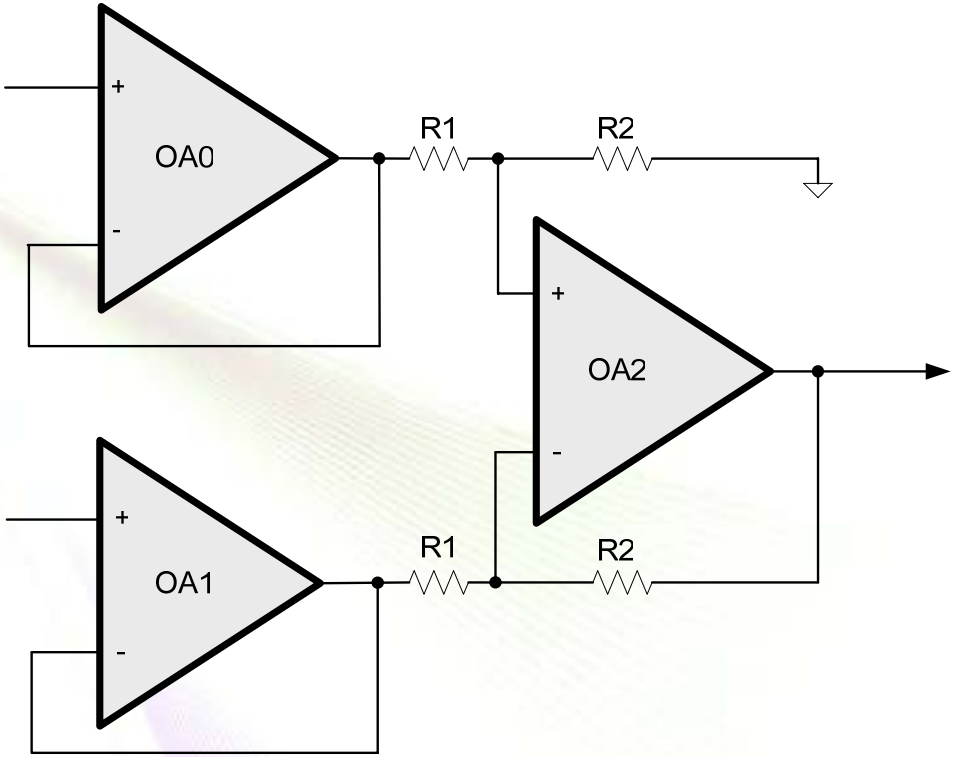

```
OA0CTL1 = OAFC_0;
OA0CTL0 = OAN_0 | OAP_1 | OAPM_3;
OA1CTL1 = OAFC_6 | OAFBR_2;
OA1CTL0 = OAN_2 | OAP_0 | OAPM_3 | OAADC1;
```

2-amp differential amplifier




```
OA0CTL1 |= OAFC_7 | OAFBR_0;  /* Differential mode */
OA0CTL0 |= OAP_2 | OAPM_3;
OA1CTL1 |= OAFC_6 | OAFBR_2;  /* Inverting PGA mode */
OA1CTL0 |= OAP_3 | OAN_2 | OAPM_3 | OAADC1;
```

3-amp differential amplifier




```
OA0CTL1 |= OAFC_1 | OAFBR_2;   /* Unity gain mode */
OA0CTL0 |= OAP_2 | OAPM_3;
OA1CTL1 |= OAFC_7 | OAFBR_0;   /* Differential mode */
OA1CTL0 |= OAP_3 | OAPM_3;
OA2CTL1 |= OAFC_6 | OAFBR_2;   /* Inverting PGA mode */
OA2CTL0 |= OAP_3 | OAN_3 | OAPM_3 | OAADC1;
```

In conclusion…

- Flexible modes, to optimize current consumption & performance
- User configurable as general purpose, unity gain, voltage comparator, inverting & non-inverting PGA, differential
- Internally connected to ADC and DAC
- Highly configurable & suitable for portable medical system requirements

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