Experiment Design and Data Analysis

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Goals

Learn to

- Design an experiment
- Make measurements
- Analyze and interpret data

Problem

Need to *accurately* determine the **gain** of an amplifier as a function of frequency

50Ω, 20 MHz to 6 GHz

Features
- Wide Bandwidth, 20 MHz to 6 GHz
- Low Noise Figure, 3.3 dB Typ.

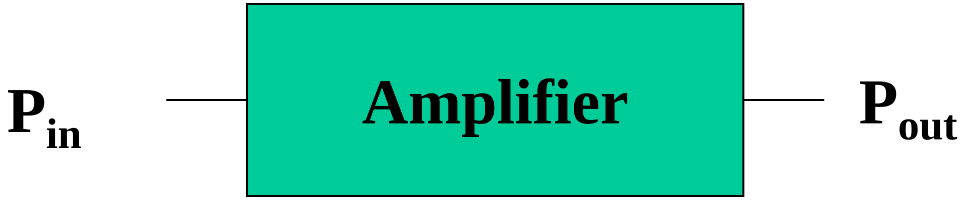
Connectorized
Amplifier

ZX60-6013E+

Mini-Circuits®
ISO 9001 ISO 14001 CERTIFIED

What is gain?

Gain is the ratio of power out to power in



$$G = P_{out} / P_{in}$$

$$G(dB) = P_{out}(dBm) - P_{in}(dBm)$$

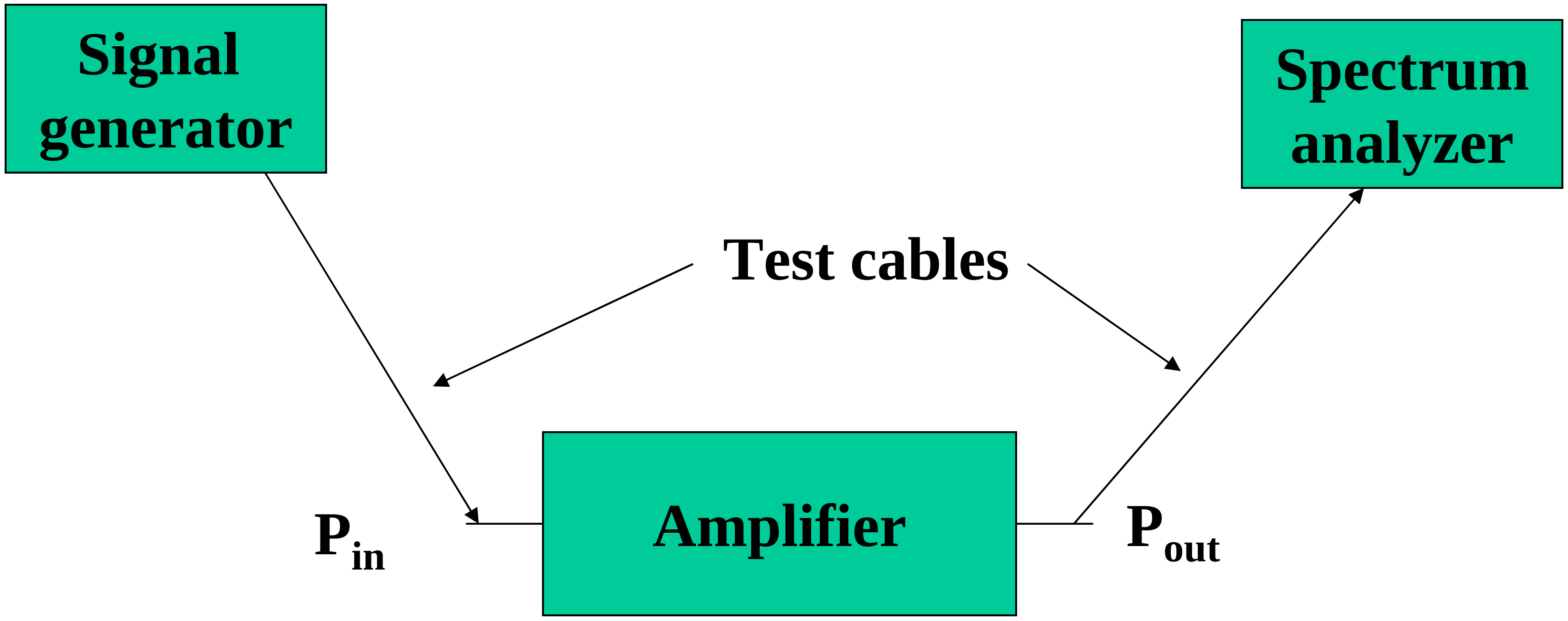
Issues to consider

Gain may depend on

- Frequency of input signal
- Power level of input signal
- Voltage used to power the amplifier
- Temperature
- ????????

Need to identify and control the variables!!!

Experimental set up



Experimental set up: design issues

- Does the power generated by the signal generator change with frequency?
- Will the losses in the test cables change with frequency?
- Is the spectrum analyzer calibrated?

How can we make an accurate and precise measurement??

Accuracy and Precision

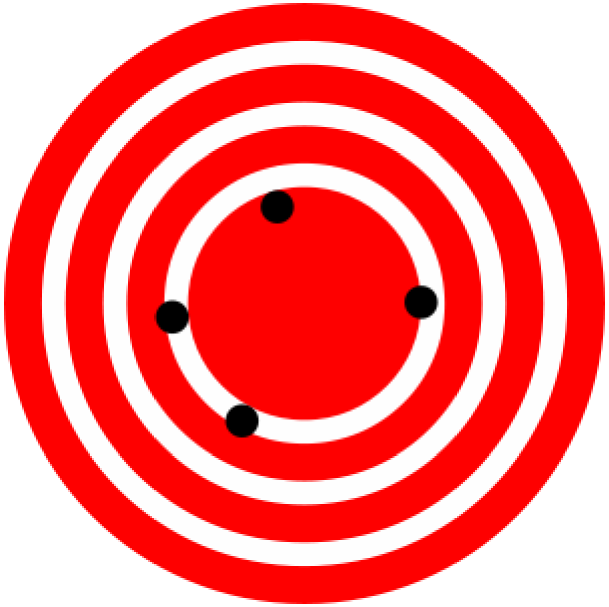
Accuracy is the degree of conformity of a measured or calculated quantity to its actual (true) value.

Precision, also called reproducibility or repeatability, the degree to which further measurements or calculations show the same or similar results.

The results of calculations or a measurement can be accurate but not precise; precise but not accurate; neither; or both. A result is called *valid* if it is both *accurate* and *precise*.

Source: Wikipedia

High Accuracy and Low Precision

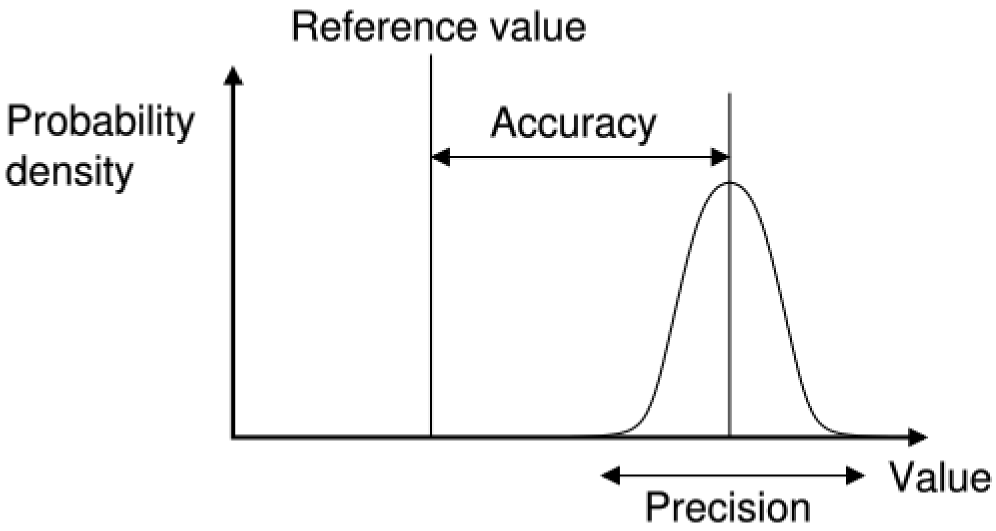


Source: Wikipedia

Low Accuracy and High Precision

Source: Wikipedia

Accuracy and Precision



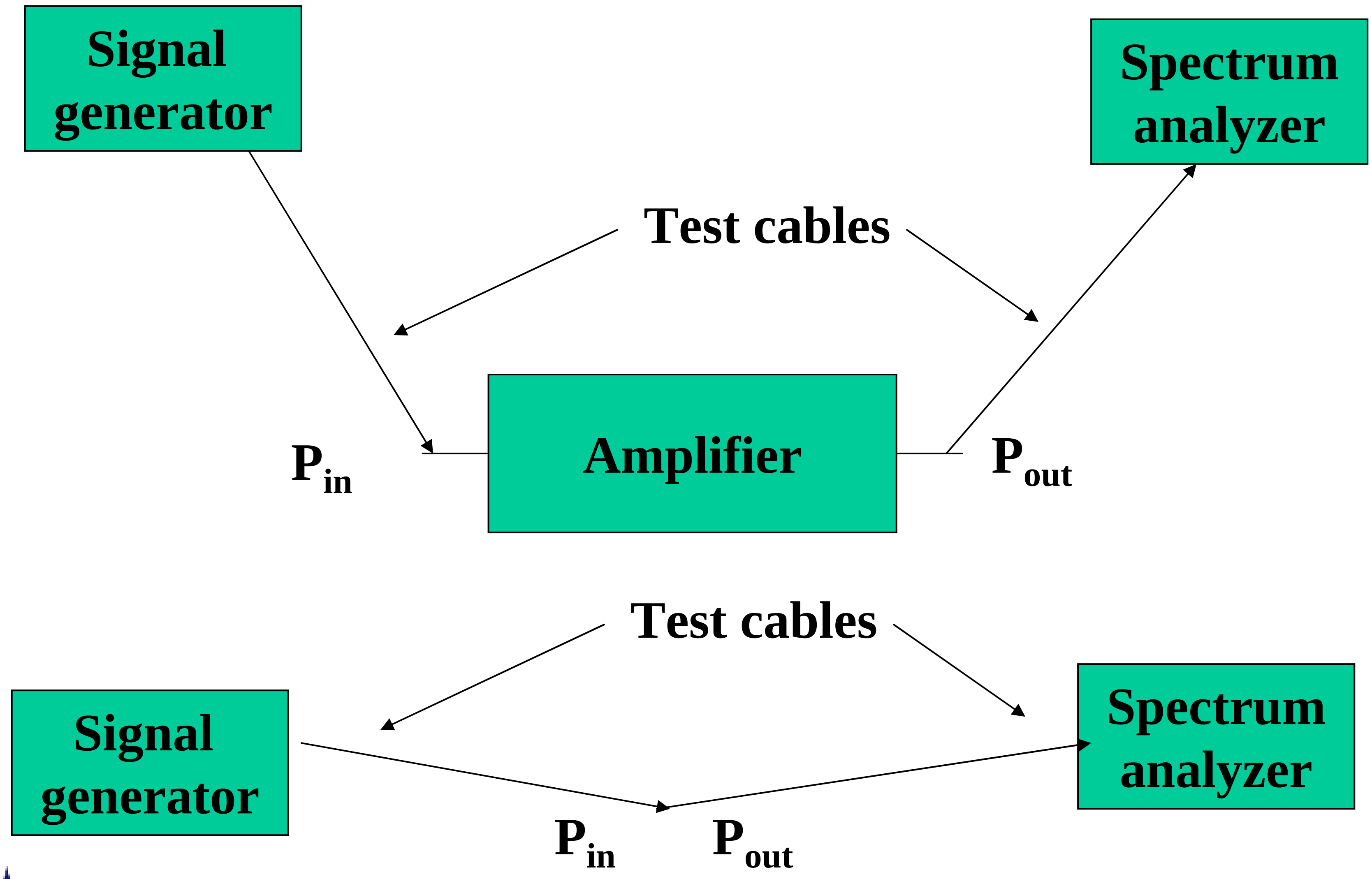
Source: Wikipedia

Quantifying Accuracy and Precision

- Ideally a measurement device is both accurate and precise, with measurements all close to and tightly clustered around the known value.
- The accuracy and precision of a measurement process is usually established by repeatedly measuring some tracable reference standard.
- Such standards are defined in the International System of Units and maintained by national standards organizations such as NIST.

Source: Wikipedia

Procedure to control the variables



Measurement procedures

1. Select a frequency f and input power level for the signal generator
2. Set the spectrum analyzer to the same frequency
3. Connect the output cable to the input cable and use the spectrum analyzer to measure $P=P_{in}$
4. Insert the amplifier between the input and output cables and use the spectrum analyzer to measure $P=P_{out}$
5. $G\ (dB) = P_{out}(dBm) - P_{in}(dBm)$
6. Repeat steps 3-5 and calculate G_{ave} and standard deviation of G: σ_G
7. Go back to step 1 and choose a new frequency

Average and standard deviation

Average:

Make N measurements of G at frequency f.

The G_{ave} is given by

$$\overline{G} = \frac{1}{N}\sum_{i=1}^{i=N} G_i$$

Average: example

Make 5 measurements of G at frequency f.

G= 10.1, 10.6, 10.3, 10.7, 10.4dB

Then G_{ave} = (1/5)[10.1+10.6+10.3+10.7+10.4]

G_{ave} = (1/5)(52.1) = 10.42dB

Standard deviation

Standard deviation σ is a measure of the precision, or “spread” of the data around the average.

Suppose $\overline{\mathrm{G}}$ is the average value of the gain, G for N measurements

Then the standard deviation of G, called σ_{G} is given by

$$\sigma_{\mathrm{G}} = \sqrt{\frac{1}{N}\sum_{i=1}^{i=N}\left(G_i - \overline{G}\right)^2}$$

Standard deviation: example

Standard deviation σ is a measure of the precision, or “spread” of the data around the average.

Average and standard deviation: example

Make 5 measurements of G at frequency f.

G= 10.1, 10.6, 10.3, 10.7, 10.4dB

Then G_{ave} = (1/5)[10.1+10.6+10.3+10.7+10.4]

G_{ave} = (1/5)(52.1) = 10.42dB

σ_G = sqrt{(1/5){(10.1-10.42)^2+(10.6-10.42)^2+(10.3-10.42)^2+(10.7-10.42)^2+(10.4-10.42)^2}}

σ_G = sqrt{1/5{0.102+0.032+0.014+0.078+0.004}}

σ_G = sqrt{0.2 (0,226)} = 0.21

Average and standard deviation: example

Result:

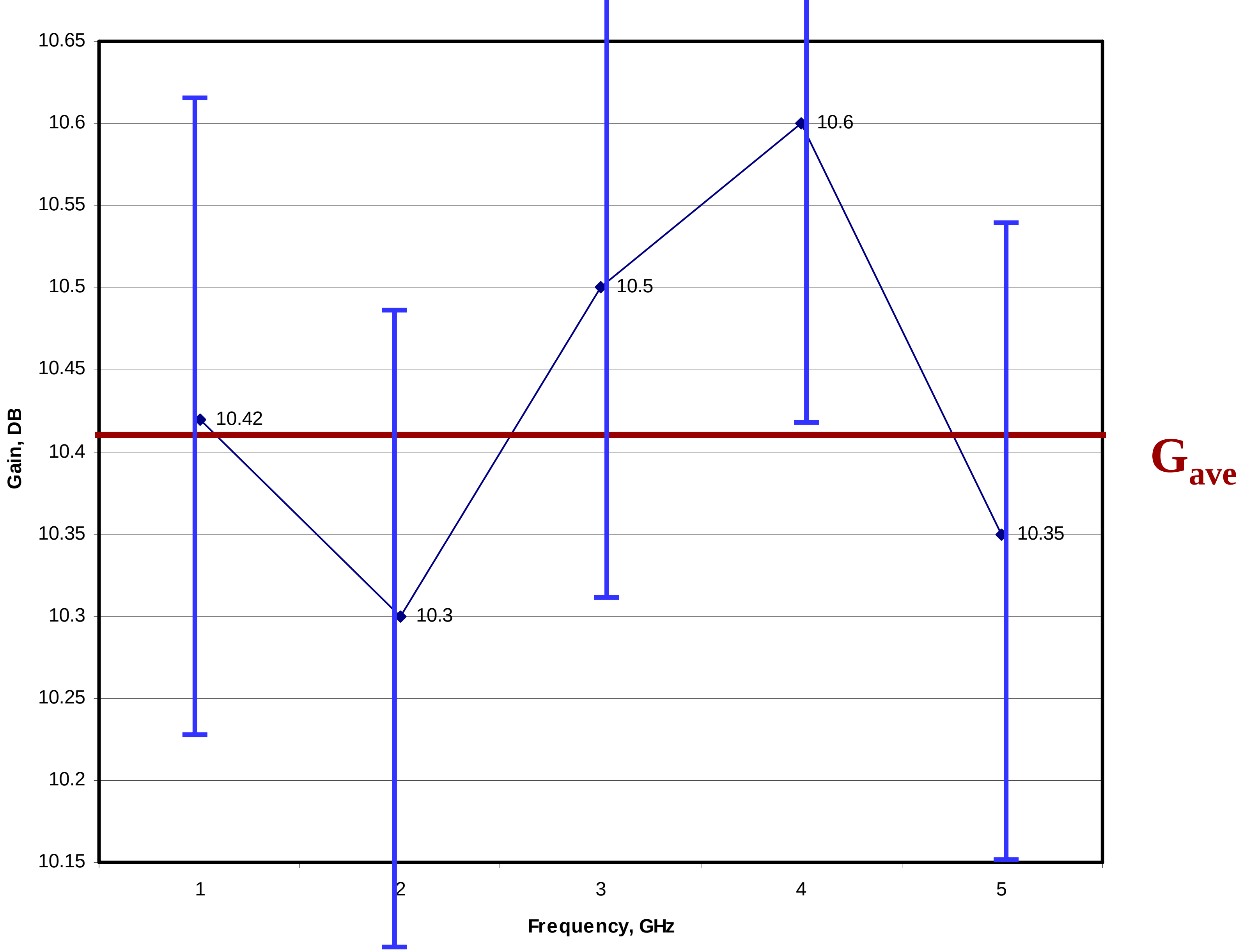
G_{ave} = 10.42 +/- 0.21 dB

Repeat procedure for additional frequencies

Suppose measure G at 1, 2, 3, 4, 5 GHz:

Results:

f (GHz)	G(dB)	s (dB)
1	10.42	0.21
2	10.3	0.17
3	10.5	0.22
4	10.6	0.19
5	10.35	0.2


10.65
10.6
10.55
10.5
10.45
10.4
10.35
10.3
10.25
10.2
10.15
Gain, DB
10.42
10.3
10.5
10.6
10.35
1
2
3
4
5
Frequency, GHz
G_{ave}

Least squares fit

Fit the average gain values to a straight line:

$$\overline{G}(f) = mf + b$$

If m ~ 0, then the gain is independent of frequency

http://www.physics.csbsju.edu/stats/least_squares.html

Least squares fit

Fit the average gain values to a straight line:

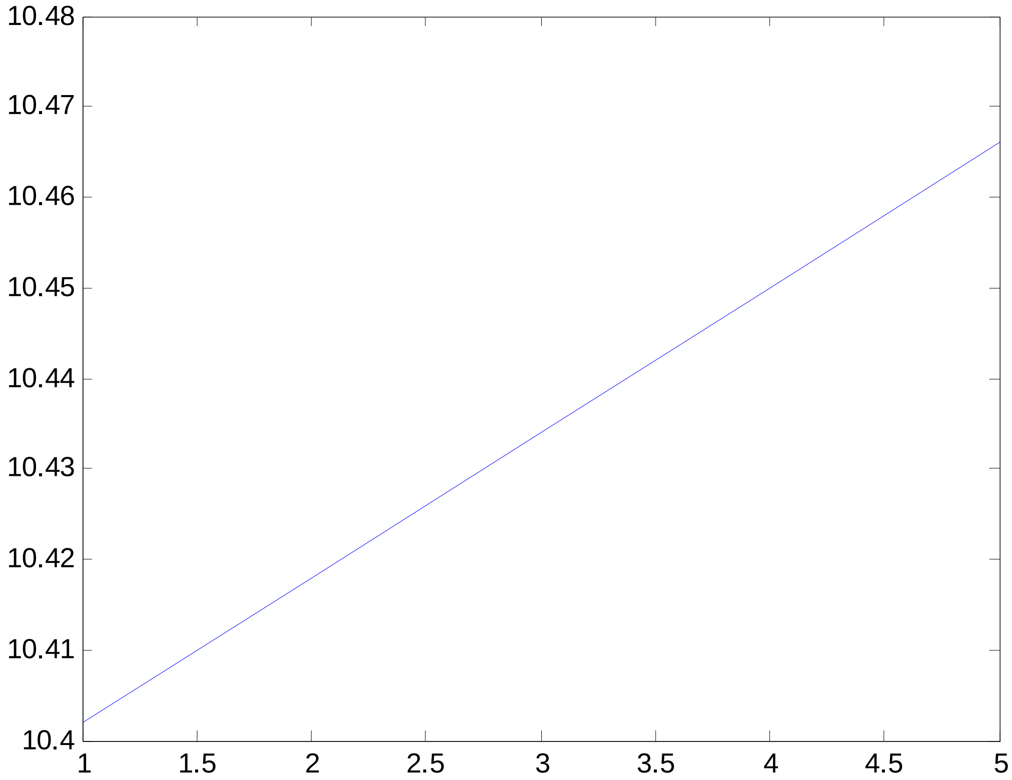
Use Matlab:

```
x=[1:5];
y=[10.42,10.3,10.5,10.6,10.35];
c=polyfit(x,y,1)
z=c(2)+x*c(1);
plot(z)
```

Results: $m = 0.0160$, $b = 10.3860$

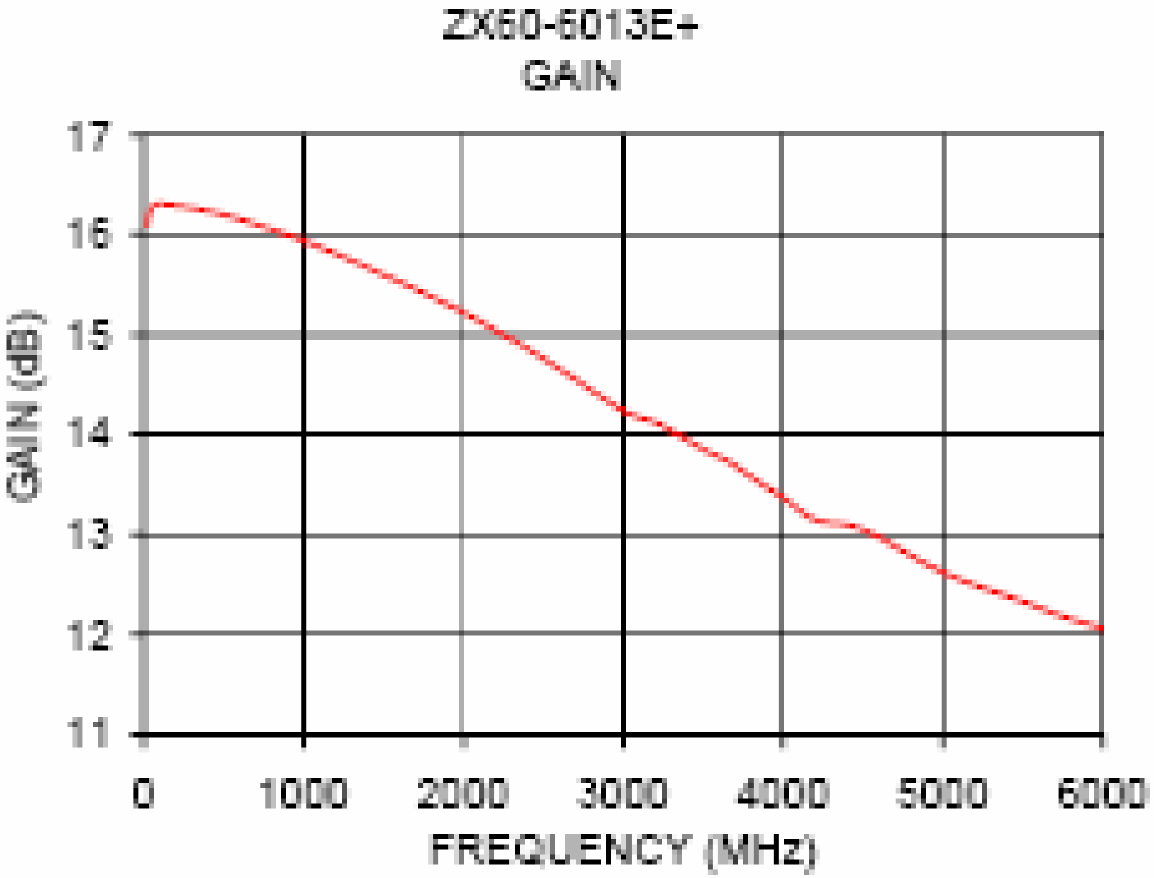
Least squares fit

Matlab Results: m = 0.0160, b = 10.3860



Conclusion:
Slight gain slope:
0.45 dB over 5 Ghz

Maufacturer’s data sheet



http://www.minicircuits.com/pdfs/ZX60-6013E+.pdf