Understanding and Measuring I/Q Crosstalk in Digital Microwave Communications Systems

Chris Pedersen
August 1988

RF & Microwave Measurement Symposium and Exhibition

HEWLETT PACKARD

ABSTRACT:

Crosstalk between the I and Q information channels of modern communication systems arises not only from poor baseband isolation, but also from IF and RF impairments such as amplitude ripple and nonlinear phase response. This paper discusses techniques to measure and quantify the combined effects of crosstalk, whereas earlier papers discussed the effects separately. It also examines the causes as well as the effects of system performance degradation.

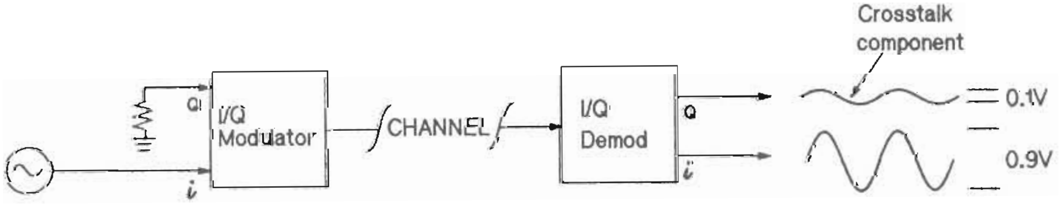
AUTHOR:

Chris Pedersen, Product Manager, Stanford Park Division,, Palo Alto, CA. BSEE 1984, Brigham Young University. Joined HP in 1984 as Product Marketing Engineer responsible for developing vector modulation applications.

Understanding and Measuring I/Q Crosstalk in Digital Microwave Communication Systems

1. What is I/Q Crosstalk?
2. What causes I/Q Crosstalk?
3. How do transfer function amplitude and group delay asymmetries cause I/Q Crosstalk?
4. Measuring I/Q Crosstalk
   a. Through the system
   b. Through a demodulator
   c. Through a modulator
5. Relating I/Q Crosstalk to C/N degradation
6. Summary

What is I/Q Crosstalk?

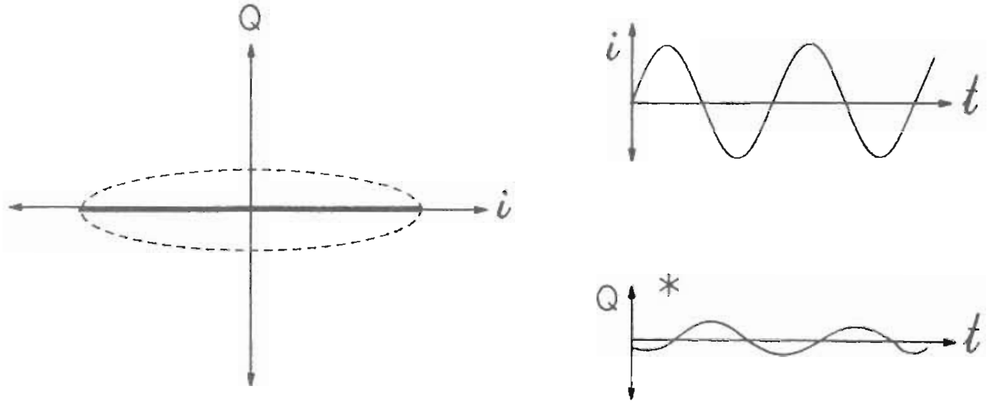


I/Q Crosstalk is an effect which results in unwanted I or Q signal appearing on the Q or I channel respectively.

$$\text{I/Q Crosstalk} = \frac{\text{Cross-coupled signal level}}{\text{Total signal level}}$$

$$\text{eg. I/Q Crosstalk} = \frac{0.1V}{\sqrt{(0.1V)^2 + (0.9V)^2}} = 0.11 \text{ or } 11\% \text{ or } -19.1 \text{ dB}$$

Crosstalk in the Vector Diagram



*The phase of the cross-coupled signal varies depending on the *cause* of the crosstalk.

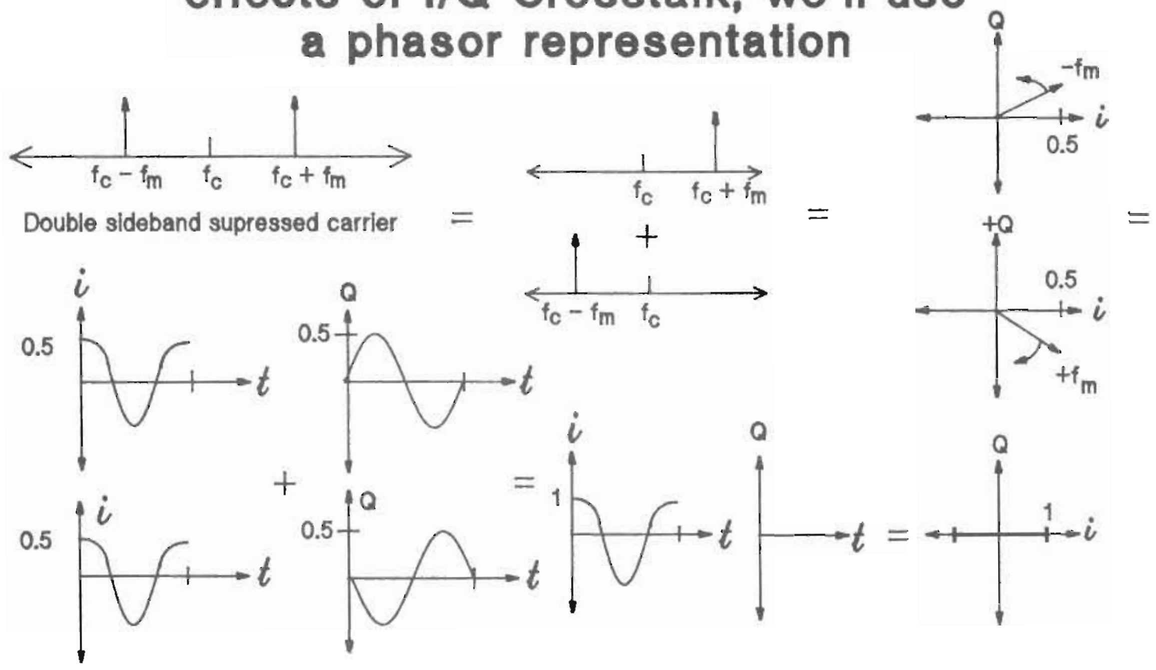
What causes I/Q Crosstalk?

1. Transfer function amplitude and group delay which are asymmetrical about the channels center frequency cause I/Q Crosstalk.

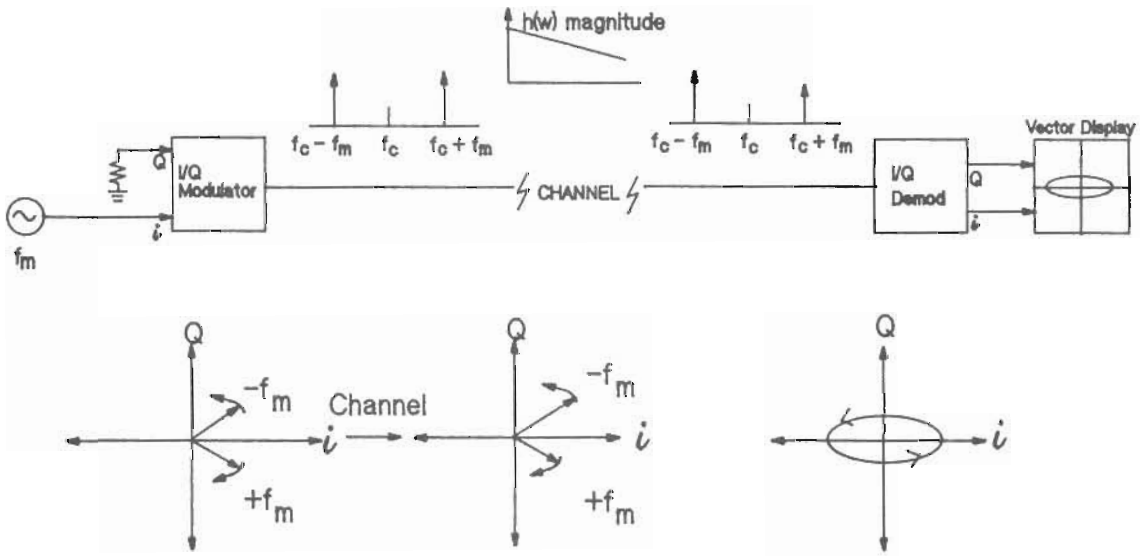
2. Symmetrical transfer function imperfections cause ISI but not I/Q Crosstalk.

3. As defined in this paper, I/Q Crosstalk doesn't include the effects of non-linear V_{OUT}/V_{IN} characteristics such as AM-AM and AM-PM. Linear V_{OUT}/V_{IN} characteristics are assumed and the measurement/analysis techniques presented are inappropriate for substantially nonlinear V_{OUT}/V_{IN} devices such as HPAs.

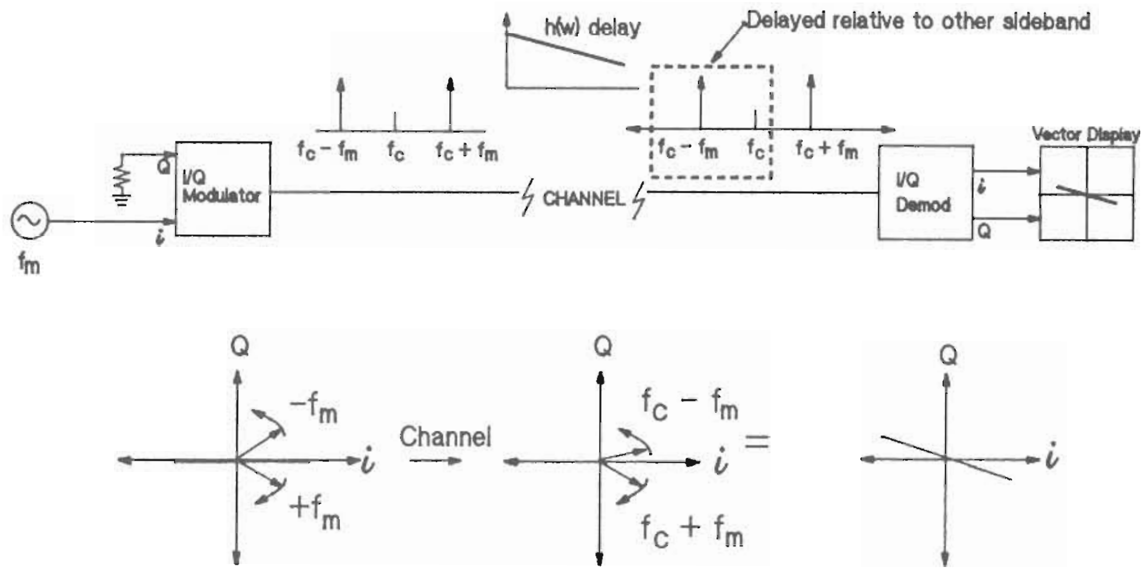
To help understand the causes and effects of I/Q Crosstalk, we'll use a phasor representation



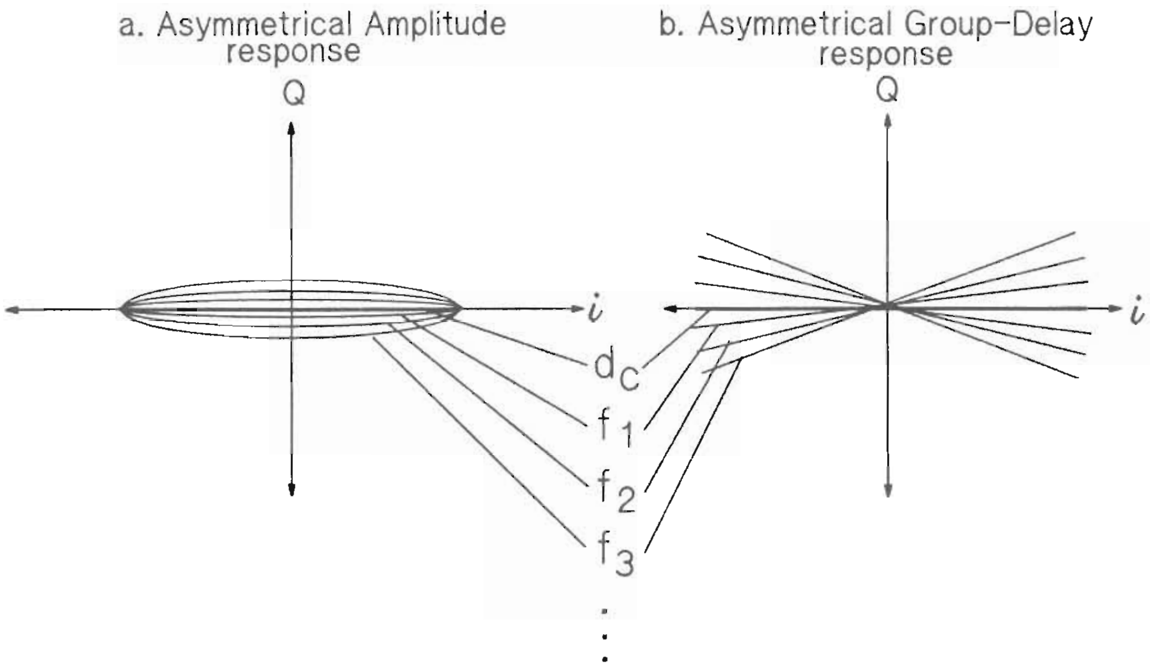
How do transfer function amplitude and group delay asymmetries cause I/Q Crosstalk? eg. Asymmetrical Amplitude Response



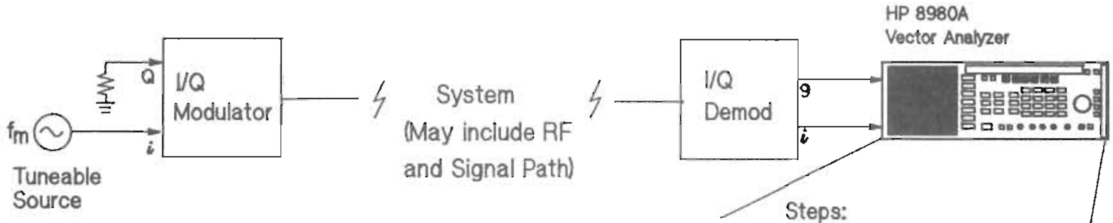
How do transfer function amplitude and group delay asymmetries cause I/Q Crosstalk? eg. Asymmetrical Group Delay Response



What does I/Q Crosstalk look like in the Vector diagram for broad band systems?

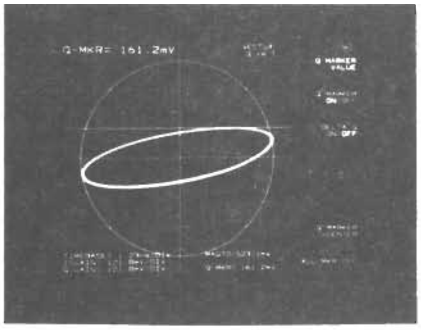


Measuring I/Q Crosstalk Through the System

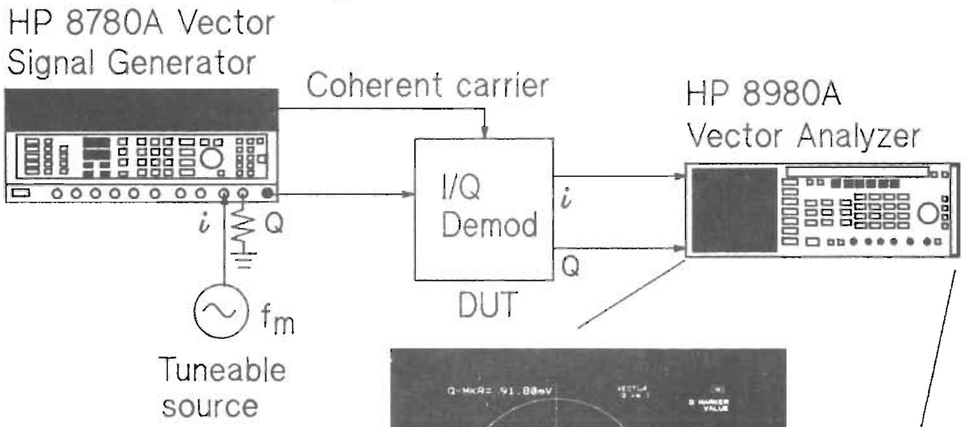


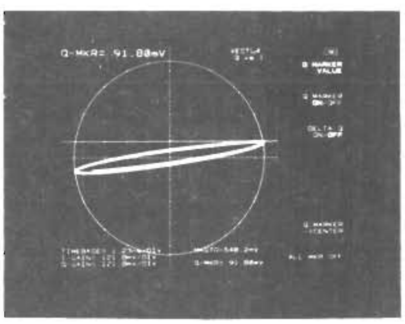
Steps:

1. Adjust Phase Offset with $f_m = 0$
2. Tune f_m and measure I/Q Crosstalk with markers.

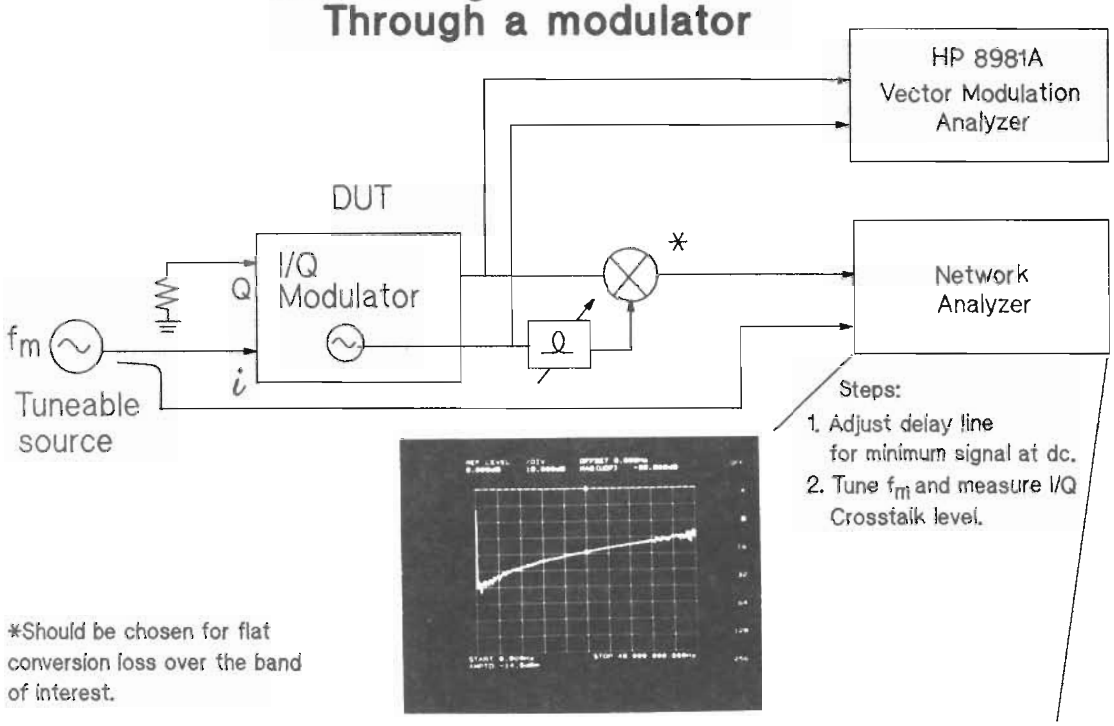


Measuring I/Q Crosstalk Through a demodulator





Measuring I/Q Crosstalk Through a modulator



*Should be chosen for flat conversion loss over the band of interest.

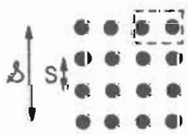
Relating I/Q Crosstalk to C/N Degradation

When I/Q Crosstalk % is $<< 10^{-\left(\frac{c/n}{20}\right)}$ this "Moving the states closer together" is effectively the same as reducing the state spacing by the *I/Q Crosstalk fraction*.

This corresponds to a C/N degradation of:

$$-20 \log \left(\frac{\text{State separation} - \text{Crosstalk}}{\text{State separation}} \right)$$

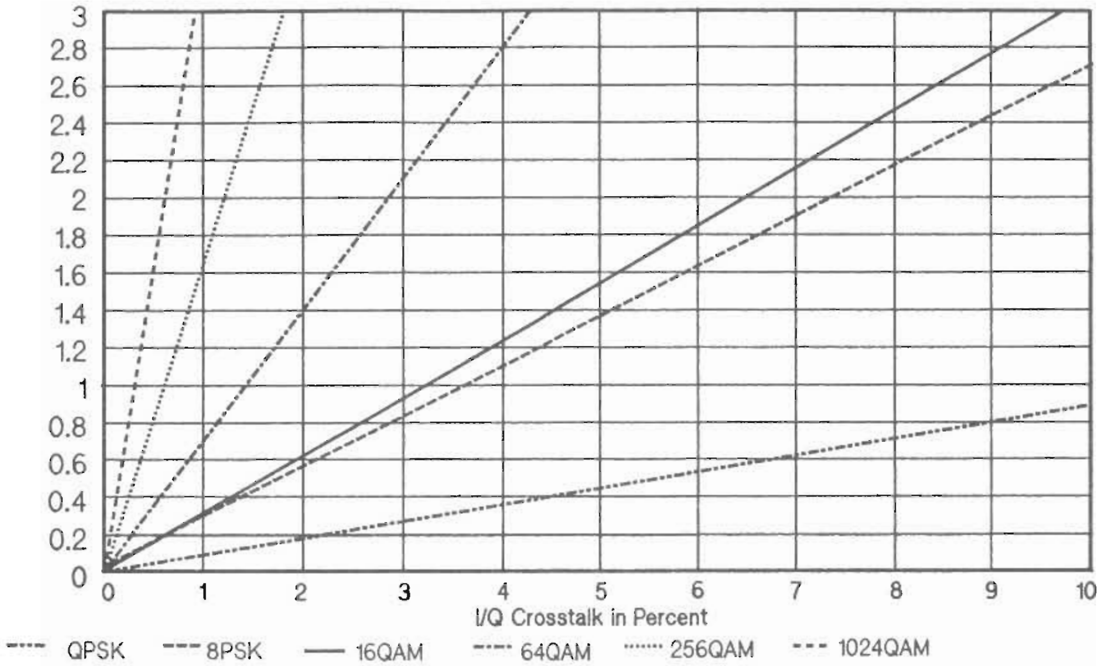
Where state separation is the voltage difference between adjacent modulation states prior to Crosstalk degradation divided by the maximum modulation state I or Q component voltage (for square modulation formats



State separation $= \frac{s}{\delta}$

C/N Degradation due to I/Q Crosstalk

for Xtalk % <<100 x 10^(-C/N/20)



Comparing I/Q Crosstalk predictions with amplitude and group delay error predictions

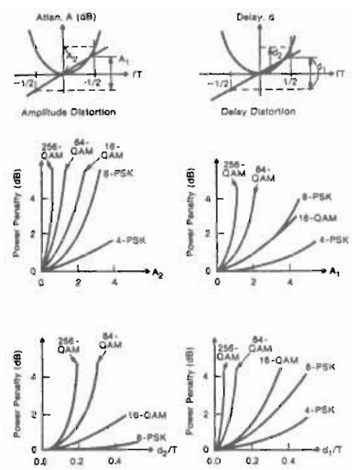


Fig. 7. Power penalties due to linear distortions (BER = 10⁻⁴).

From "Modulation techniques for Digital Microwave Radio" by Toshitake Noguchi, Yoshimasha Daido, Joseph A. Nossek. and Joseph A. Nossek. IEEE Communications Magazine 10/86

Eg. 64QAM with ideal Nyquist BW. Since only asymmetrical errors cause Crosstalk we'll compare linear slope predictions.

1. Delay distortion with $\frac{d1}{T} = 0.1$

from graph at left c/n degrades $\simeq$ 2.8 dB

I/Q Crosstalk = Sin (0.1 rad)

$\simeq$ 0.1 or 10%

which correlates to 10 dB c/n degradation

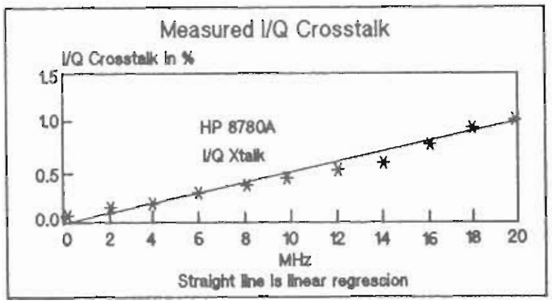
Modulation	Error	Channel impairment prediction	Xtalk prediction
QPSK	$A_1 = 1.0$	$\simeq 0$	1.1 dB
	$d_1 = 0.1$	0.1 dB	0.93 dB
	$A_1 = 1.0$	0.16	3.9 dB
16QAM	$d_1 = 0.1$	0.2	3.1 dB

I/Q Crosstalk is an extremely pessimistic predictor.

Relating I/Q Crosstalk to C/N degradation – example: HP 8780A Vector Signal Generator

*What's the HP 8780A C/N degradation due to I/Q Crosstalk when generating a 64QAM signal at a 22.5 MHz symbol rate over a 30 MHz bandwidth?

Let's assume a flat spectral distribution over 30 MHz (conservative). Then from the graph below the HP 8780A I/Q Crosstalk is linearly distributed from 0 to 0.75%.



$$\text{C/N degradation} = 20 \log \left(\frac{1/7 - .0075}{1/7} \right)$$
$$= 0.47 \text{ dB}$$

Remember: I/Q Crosstalk is an extremely pessimistic C/N predictor!

Summary

1. I/Q Crosstalk is an effect which results in unwanted I or Q signal appearing on the Q or I channel respectively.
2. I/Q Crosstalk is caused by amplitude and group delay asymmetries.
3. I/Q Crosstalk is directly measureable through modulators and demodulators using off-the-shelf equipment.
4. Although I/Q Crosstalk is *NOT* easily related to C/N degradation, it's a sensitive measure of imperfections critical to C/N performance.
5. The HP 8780A I/Q Crosstalk performance results in *VERY* low C/N degradation making it an excellent choice for receiver testing.