4. Radio Performance

This chapter presents the performance of the radio.

4.1 Transmitter

4.1.1 Transmit Power

W-CDMA test signals were not available. Therefore, the transmit power is measured on the continuous-wave (CW) output. The QPSK modulation is equivalent a single-sideband generator, if the direct (I) and quadrature (Q) signals are the same but the I signal leads the Q signal by 90°. A modulation generator was built as shown in Figure 52 for generating the test carrier. The generator produces two TTL compatible square waves. The square waves are 90° out-of-phase. The frequency of the square waves is 1.25MHz which is inside the passband of the baseband filters.

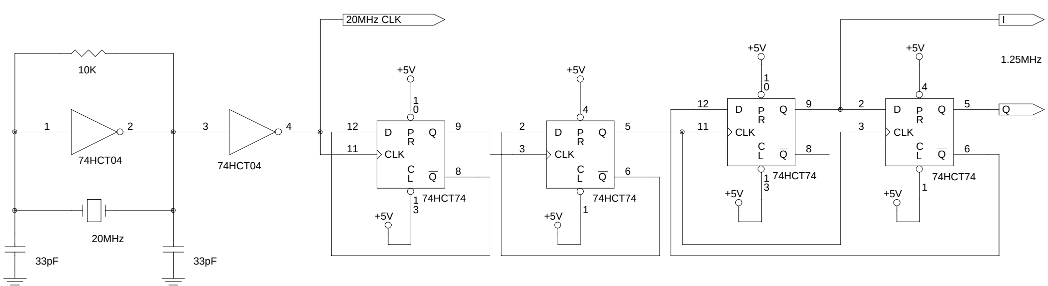


Figure 52. Modulation generator.

The square waves are fed to the DAC board of the transmitter. The phase-lead square wave is applied to the I channel DAC. All the input pins of the DAC are tied together. This provides the codes between 00000000B and 11111111B to the DAC. The output of the DAC is a 0.5V square wave. The baseband filter removes the harmonics of the DAC output and provides a 1.25MHz tone signal. Similarly, a 1.25MHz tone, which is 90° phase lag, is generated on the Q channel.

The two tones are fed to the transmitter modulator to generate the single-sideband CW output. The CW output is 1.25MHz away the modulator LO as shown in Figure 53. After the power amplification, the CW output can be measured for the transmit power. Figure 54 shows the measurement setup.

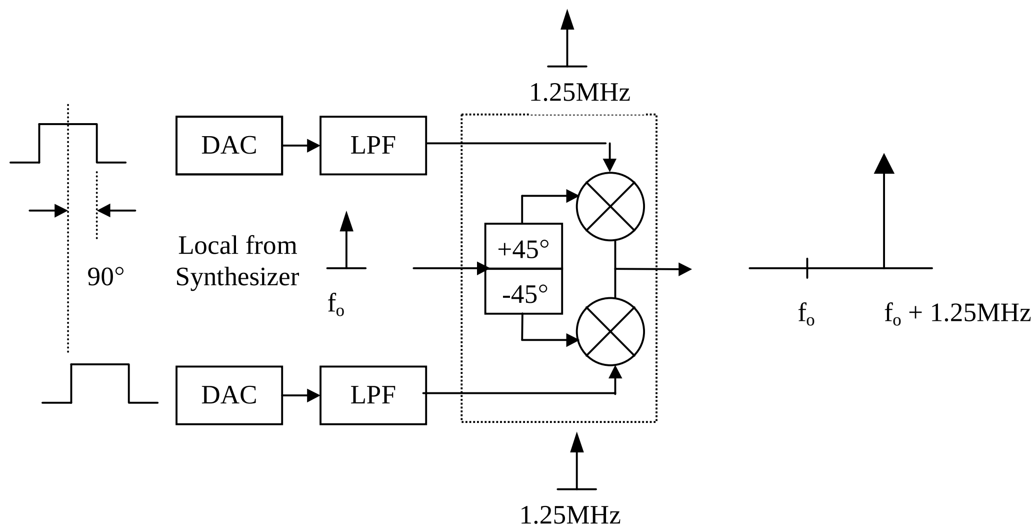


Figure 53. Single-sideband generation.

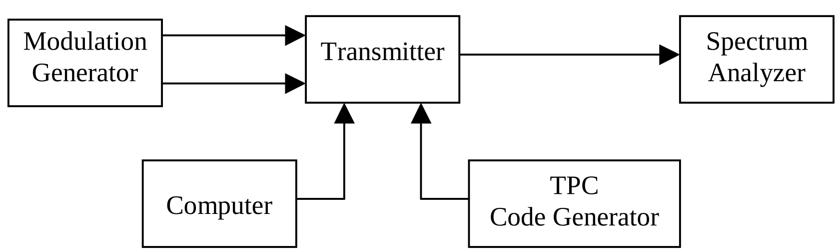


Figure 54. Transmit power test setup.

The computer is used to load the commands to the synthesizer for setting the channel of the radio. The test is conducted on the middle channel. The TPC code generator provides the command code to set the transmit power level. The modulation generator provides the signals for the single-sideband generation. The spectrum analyzer measures the transmitter output.

Measurement Procedure:

1. Set the transmitter to operate on the middle channel (i.e. 1952.5MHz).
2. Set the TPC command code for 0 (i.e. 0000000B binary).
3. Adjust the variable resistor (Appendix C-5: R18) in the AFC board for the maximum transmit power, approximately 32dBm.
4. Set the TPC command code for 70 (i.e. 1000110B binary).
5. Adjust the variable resistor (Appendix C-5: R19) in the AFC board for the 70dB transmit power attenuation.
6. Repeat the procedure 2 to 5 until the maximum transmit power and the 70dB transmit power attenuation are simultaneously obtained.
7. Measure the single-sideband output with the spectrum analyzer for the transmit power.

Figure 55 shows the output spectrum of the transmitter.

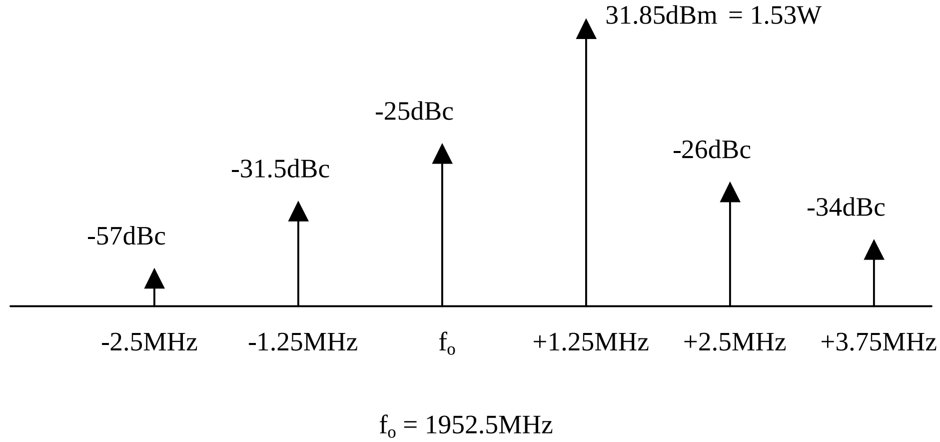


Figure 55. Transmitter output power spectrum.

The output power meets the specification of 1.6W +20% -50%. This is the measured data of the single-stage power amplifier design. This design can provide sufficient transmit power but fails the adjacent channel power specification.

Figure 56 shows the test setup for the adjacent channel power measurement. Figure 57 is the measured spectrum of the QPSK modulated transmit signal.

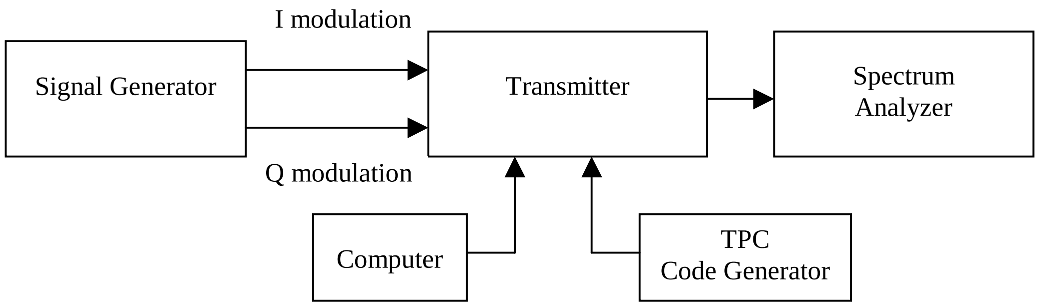


Figure 56. Adjacent channel power test setup.

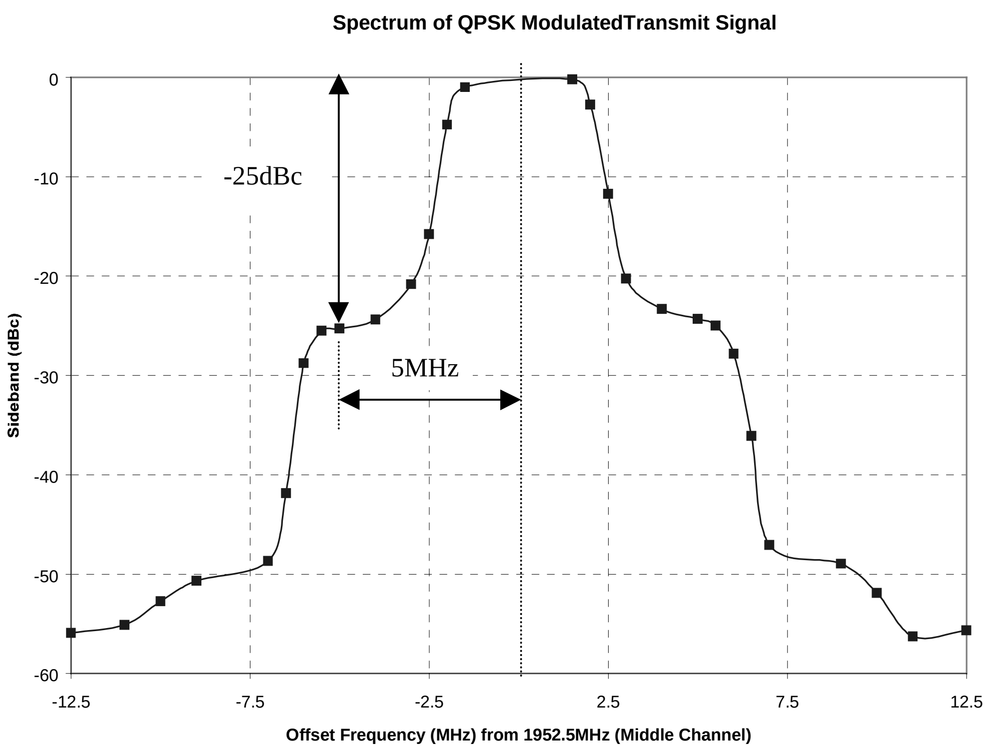


Figure 57. The measured spectrum of the QPSK modulated transmit signal.

The signal generator is HP4433B. The generator is an RF signal generator but it also provides the analog I and Q filtered baseband signals at its back panel. The symbol rate was 4.096Msps and the 0.22 roll-off square root raised cosine pulse shaping was applied on the symbols. Since the baseband signals were in analog form, the signals were fed to the transmitter modulator instead of the digital interface. The modulator output was set to –2dBm to minimize the adjacent channel power generated by the single-stage power amplifier. The modulator output less than –2dBm could not deliver the required transmit power. However, the adjacent channel power was –25dBc as shown in Figure 57. The adjacent channel power is higher the specification of –40dBc.

A two-stage power amplifier design is being considered to improve the adjacent channel power suppression as mention in Section 3.1.4.4. The design improvement is in progress. The test data is not available at the time of this writing.

4.1.2 Transmit Power Control (TPC)

The test setup in Figure 54 is applicable to this measurement.

Measurement Procedure:

1. Set the transmitter to operate on the middle channel (i.e. 1952.5MHz).
2. Set the TPC command code for 0 (i.e. 0000000B binary) for the maximum transmit power.
3. Record the transmitter output power and the power control voltage.
4. Increase the TPC command code by 10.
5. Repeat the procedure 3 to 4 until the command code is 70 (i.e. 1000110B binary).

Figure 58 is the measurement results.

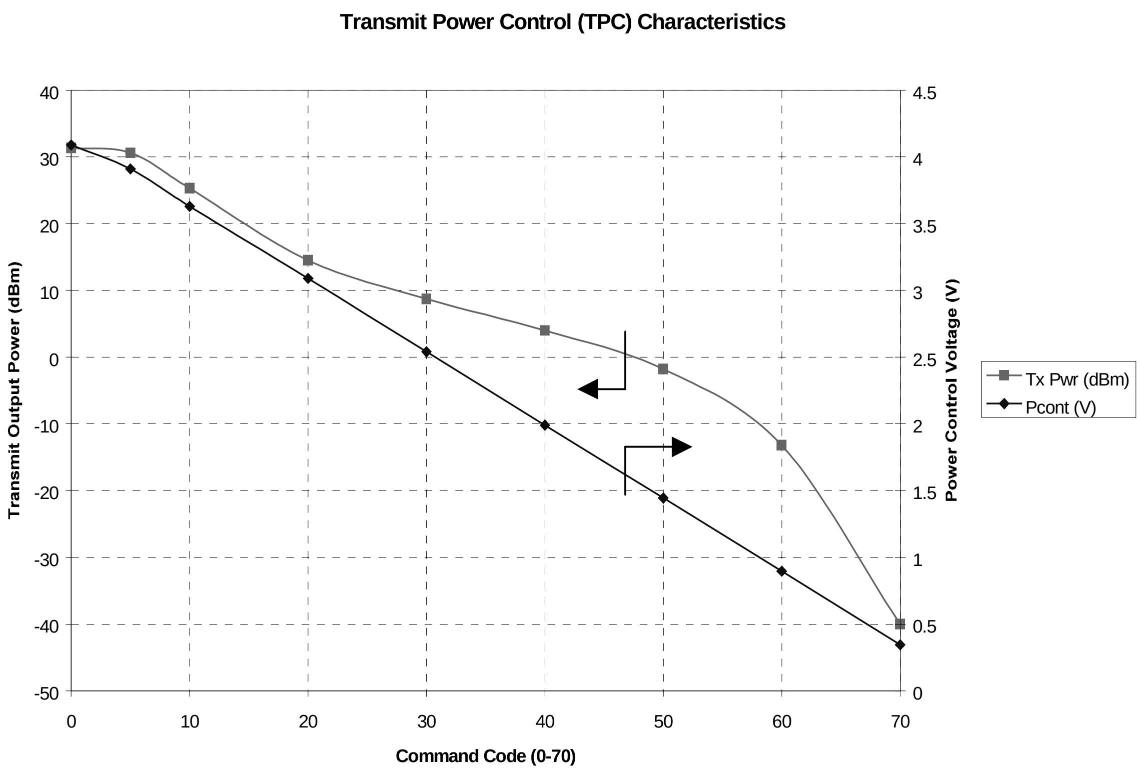


Figure 58. Transmit power control characteristic.

The transmit power control voltage curve (Pcont) shows that the transmit power control voltage responds to the command code linearly, while the transmit power curve (Tx Pwr) shows that the transmit output power responds to the command code non-linearly. The transmit power behaves non-linearly because of the non-linear attenuation-to-voltage characteristic of the AT-108 attenuators. However, the transmit output power has a monotonic decrease characteristic. The objective of the power control can be performed. Also, the control range meets the 70dB specification.

4.2 Receiver

4.2.1 Receiver Noise figure

Without the W-CDMA base station, it is not possible to do a direct measurement of sensitivity. Therefore, the minimum detectable signal (MDS) is measured to estimate the noise figure of the receiver. The MDS is an RF input level at the receiver so that the receiver analog output is equal to the noise output. The noise figure can be approximately estimated by

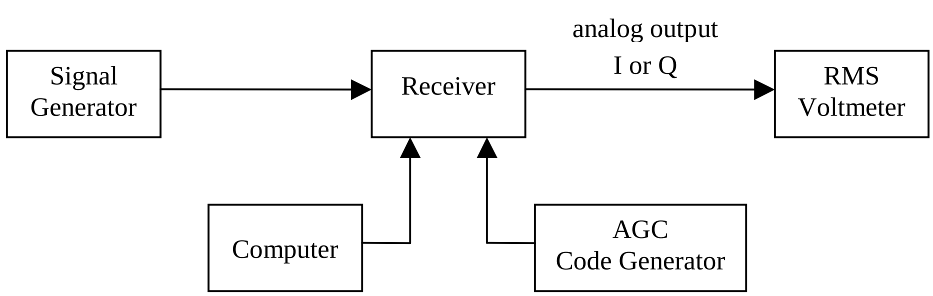
$$NF(dB) = MDS(dBm) + 174(dBm) - 10 \cdot \log B(dB) \tag{4.1}$$

where

B : is the channel bandwidth of 5MHz.

174 dBm : is the thermal noise power.

Compare the estimated noise figure to the desired noise figure of 5.4dB (Section 3.2.3.1) for a confidence of the receiver sensitivity. The measurement setup is shown in Figure 59.



RMS – Root Mean Square

Figure 59. Receiver sensitivity test setup.

The computer is used to set the channel of the radio. The test is conducted on the middle channel. The AGC code generator provides the command code to set the receiver gain.

The signal generator provides the RF test signal. The receiver output is the I or Q analog signal from the receiver. The root-mean-square (RMS) voltmeter measures the receiver output.

Measurement Procedure:

1. Set the receiver to operate on the middle channel (i.e. 2142.5MHz).
2. Set the AGC command code for 80 (i.e. 1010000B binary) for the minimum receiver gain.
3. Set the output frequency of the signal generator for 2142.6MHz and the output level for -33dBm. Offset the frequency of the signal generator by 100KHz to produce a 100KHz tone at the I and Q analog outputs for measurement.
4. Measure the I (or Q) analog output with the RMS voltmeter. Adjust the variable resistor (Appendix C-4: R29 or R30) in the AGC board for 350mVrms (or 1Vpp) analog output.
5. Set the RF level of the signal generator for –113dBm and turn off the RF output.
6. Set the AGC command code for 0 (i.e. 0000000B binary) for the maximum receiver gain.
7. Measure the I (or Q) analog output with the RMS voltmeter. It measures the noise level in the receiver.
8. Turn on the RF output of the signal generator.
9. Increase the RF level of the signal generator until the RMS reading increases by 3dB. The 3dB increase means that the power of the receiver output is equal to the noise power. The RF output level of the signal generator is equal to the MDS of the receiver.

The measured MDS is approximately –102dBm and gives 5dB noise figure.

4.2.2 AGC Performance

The test setup in Figure 59 is applicable to this measurement.

Measurement Procedure

1. Set the receiver to operate on the middle channel (i.e. 2142.5MHz).
2. Set the AGC command code for 80 (i.e. 1010000B) for the minimum receiver gain.
3. Set the output frequency of the signal generator for 2142.6MHz and the output level for -33dBm. Offset the frequency of the signal generator by 100KHz to produce a 100KHz tone at the I and Q analog outputs for measurement.
4. Measure the I (or Q) analog output with the RMS voltmeter. Adjust the variable resistor (Appendix C-4: R29 or R30) in the AGC board for 350mVrms (or 1Vpp) analog output.
5. Increase the AGC command code by 5.
6. Reduce the output level of the signal generator to restore the analog output level of procedure 4.
7. Record the output level of the signal generator, and the voltages of the front-end and back-end AGC drivers.
8. Repeat the procedure 5 to 7 until the I analog output is too noisy to measure. It is likely at the command code of 5 (i.e. 0000101B binary).

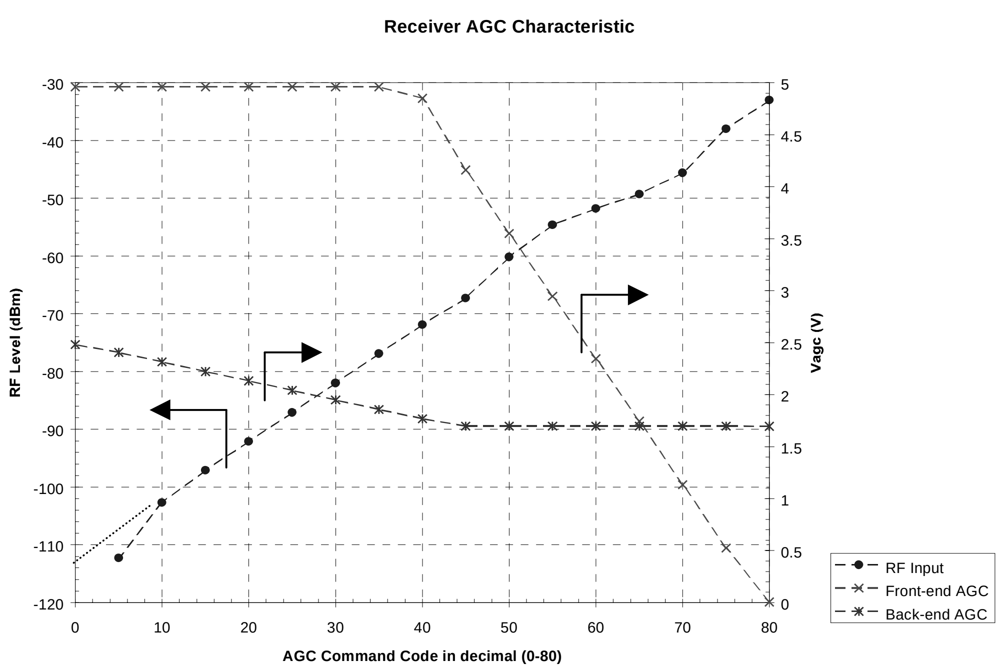


Figure 60. AGC performance.

The curves of the front-end AGC driver voltage (Front-end AGC) and the back-end AGC driver voltage (Back-end AGC) show that the performance of the AGC drivers matches the PSPICE simulation result shown in Figure 41.

The receiver RF input power curve (RF Input) shows that the back-end AGC of the receiver responds to the command code linearly but the front-end AGC behaves non-linearly. The back-end AGC operates at the 70MHz IF frequency, while the front-end AGC operates at the 2142.5MHz RF frequency. The device linearity is better at the low frequency than at the high frequency. The analog output becomes too noisy to measure as the RF input level is less than –100dBm. However, interpolating the curve for the RF input power level at the zero AGC command code shows that the level is –113dBm and meets the design target of 80dB control range.

4.2.3 Receiver Desense

The receiver desense is measured based on the minimum detectable signal (MDS) degradation. The setup in Figure 59 is applicable to the this measurement. The MDS of the receiver, when the transmitter is turned off, is measured to be -102dBm. The transmitter is turned on and the MDS measurement is repeated. The difference of the MDS readings is the receiver desense. The measurement shows no observable receiver desense.

4.2.4 Adjacent Channel Selectivity

The adjacent channel selectivity is measured based on the MDS comparison. The setup in Figure 59 is applicable to this measurement.

Measurement Procedure

1. Set the output frequency of the signal generator for 2147.5MHz (5MHz or 1 channel away the middle channel).

2. Turn on the transmitter of the radio.
3. Set the receiver to operate on the middle channel (i.e. 2142.5MHz).
4. Set the AGC command code for 0 (i.e. 0000000B binary) for the maximum receiver gain.
5. Turn off the RF output of the signal generator.
6. Measure the I (or Q) analog output with the RMS voltmeter. It measures the noise level in the receiver.
7. Turn on the RF output of the signal generator.
8. Increase the RF output level until the measured level of the RMS voltmeter increases by 3dB.

Compare the RF output level of the signal generator to the MDS of the receiver measured in Section 4.2.1. The difference of the readings is the adjacent channel selectivity. The measured adjacent channel selectivity is 70dB and meets the above 33dB specification. The measured 70dB adjacent channel selectivity is less than the predicted 95dB selectivity. The discrepancy is due to the board feed-through.

4.2.5 Intermodulation Selectivity

The intermodulation selectivity is measured based on the MDS comparison. Two signal generators and a power combiner are required to generate the intermodulation products. The measurement setup is shown in Figure 61.

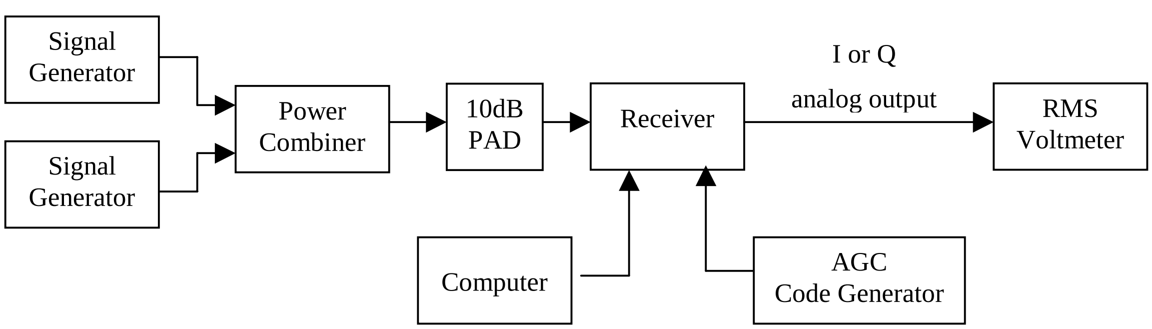


Figure 61. Intermodulation selectivity test setup.

Measurement Procedure

1. Set the output frequency of one signal generator for 2152.5MHz (10MHz or 2 channels away the middle channel) and the output frequency of the second signal generator for 2162.5MHz (20MHz or 4 channels away the middle channel).
2. Turn on the transmitter of the radio. The 10dB pad between the radio and the signal generator prevents too much transmit power from getting into the signal generator.
3. Set the receiver to operate on the middle channel (i.e. 2142.5MHz).
4. Set the AGC command code for 0 (i.e. 0000000B binary) for the maximum receiver gain.
5. Turn off the RF output of the signal generator.
6. Measure the I (or Q) analog output with the RMS voltmeter. It measures the noise level in the receiver.
7. Turn on the RF output of the signal generator.
8. Increase the RF output levels of the two signal generators and keep the generators at the same output levels. Increase the generator level until the measured level of the RMS voltmeter increases by 3dB.

Compare the RF output levels of the generators to the MDS of the receiver measured in Section 4.2.1. The difference of the readings is the intermodulation selectivity. The measured intermodulation selectivity is 62dB and meets the above 60dB specification.

4.2.6 AFC Characteristic

This measures the frequency error of the AFC output verse the AFC command code (1-127). The nominal frequency of the AFC is 140MHz. The AFC provides a ±2.2ppm control range as shown in Figure 62. This is close to the ±2ppm specification.

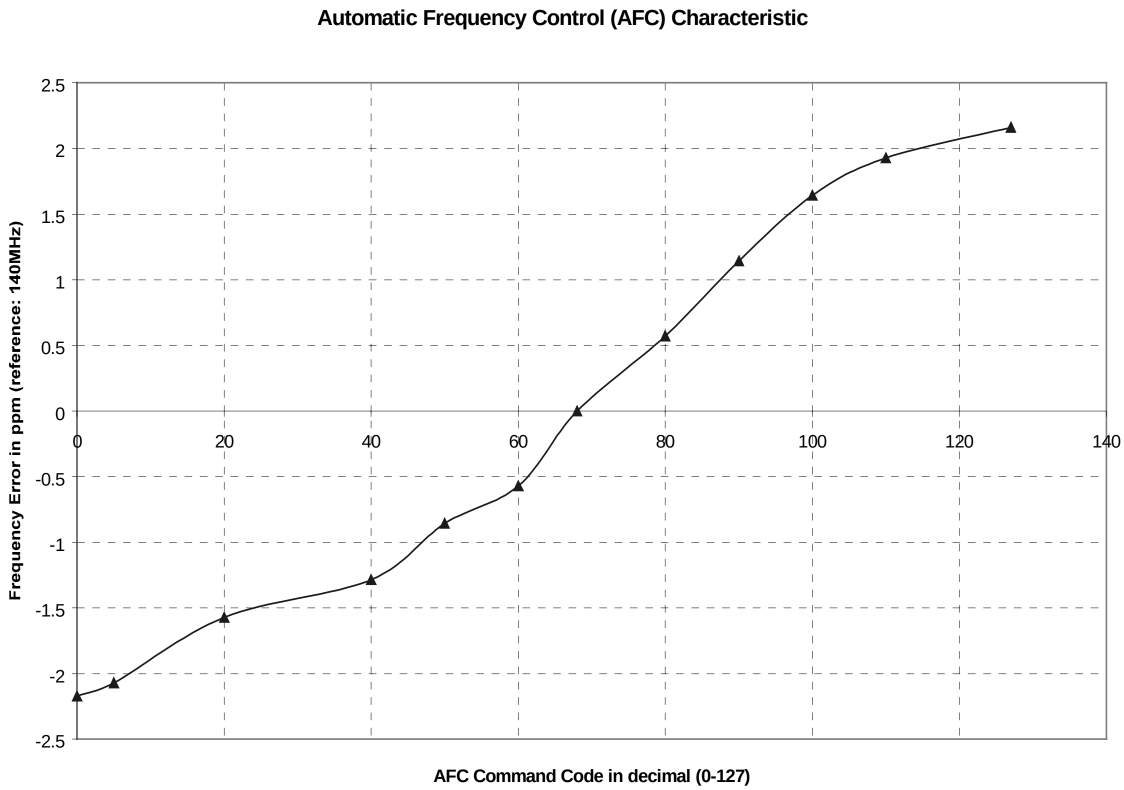


Figure 62. The AFC characteristic.