
AC 2011-1965: DEVELOPMENT OF LOW-COST RADIO FREQUENCY TEST EQUIPMENT

James O. Everly, University of Cincinnati

James O. Everly is an Associate Professor in Electronic and Computing Systems at the University of Cincinnati's College of Engineering and Applied Science. He received a BSEE and MSEE from The Ohio State University in 1969 and 1970, respectively. He is a Senior Member of the Institute of Electrical and Electronics Engineers (IEEE) and a registered professional engineer in the state of Ohio. He is a member of the IEEE Cincinnati Section, and in 1997 he received the IEEE Professional Achievement Award. He has held several research and management positions in industry working for such companies as Battelle's Columbus Laboratories, Rockwell International, and Claspan Corporation. He joined the University of Cincinnati in 1985.

Xuefu Zhou, University of Cincinnati

Xuefu Zhou received the M.S. and Ph.D. degrees in Electrical Engineering in 2002 and 2006, respectively, both from the University of Cincinnati where he joined the faculty as an assistant professor in September 2005 and became an associate professor in September 2010. From July 1995 to August 2000, he worked as a R&D Engineer, then Senior Engineer and Project Manager in the industry designing and developing distributed computer control systems, real-time embedded systems for various process controls. He is a senior member of IEEE and a member of ASEE.

Development of Low-Cost Radio Frequency Test Equipment

Abstract

This paper focuses on the construction of low-cost radio frequency test equipment which will be subsequently used to conduct performance measurements on a 7 MHz Radio Frequency (RF) transceiver. The transceiver project provides a "Project Based Learning" RF capstone experience for students in Electrical and Computer Engineering Technology. The Transceiver Project together with performance testing is structured to support course goals and objectives of "Topics of RF Communications" offered as a technical elective at the beginning of the senior year. Each student enrolled in the course is required to build and test a complete transceiver system. Students may "team-up" in groups of no more than two students for the purpose of cost sharing, but each student must contribute equally to the building and testing phases of the project.

High quality commercial RF test equipment is difficult to obtain and often limits laboratory testing activities. In this paper the author presents low-cost, easy to construct test equipment that partially circumvents this difficulty. In addition to constructing the transceiver a goal of the course is for students to execute a set of test protocols that will extract performance characteristics of the receiver portion of the transceiver. Performance parameters such as noise floor, minimum discernable signal, third-order inter-modulation intercept point, and blocking dynamic range are measured with low-cost test equipment.

An additional goal of the project is to prepare students for the upcoming Senior Design Capstone Experience required for a baccalaureate degree in engineering technology. Students are required to maintain a detailed project journal to record test results, and experiences throughout the project. To date, student feedback on this project has been very positive and a representative selection of student comments is included in the paper.

Introduction

An objective of this paper is to introduce students to RF transceiver performance standards and test procedures as described in the American Radio Relay League Performance Test Manual ^[1]. The expectation is that students learn best by doing and that transceiver "performance testing" will be an exercise in confidence building. That is, gaining confidence in the use of test equipment, confidence in properly executing the procedures, and confidence in one's ability to perform the tests and interpret the results. The effort expended by students in hardware construction and testing will offer them an opportunity to gain a "broader technical view" of the radio frequency communication process.

For the last ten years the author has been teaching a 3 credit/contact hour senior-level course in Radio Frequency Communications. The course content has changed over the last five-years based on revisions and improvements in accreditation standards. The course has changed from being mostly mathematical, to a course based on Project Based Learning which incorporates Problem Based Learning via thirty-six laboratory exercises. The author's life-long interest in

amateur radio coupled with the discovery of a textbook entitled the "Electronics of Radio" by Rutledge ^[2], based on a transceiver designed by Burdick ^[3], made the course extremely practical with emphasis on construction techniques and subsystem testing. In addition, only a modest amount on non-calculus mathematics is required for the student to gain an adequate understanding of transceiver design concepts.

Professor Rutledge's textbook uses an off-the-shelf 7 MHz RF transceiver kit known as the NorCal 40A as a vehicle for teaching RF circuit analysis and design. The term NorCal is an abbreviation for Northern California amateur radio club which initially participated in the prototype development. The transceiver is designed for continuous wave (CW) operation on 7 MHz which is more commonly known as the 40 meter amateur radio band. The "A" or improved version of the transceiver kit contains all necessary parts, building and operating instructions, together with an attractive enclosure. The transceiver is currently marketed as a kit by Wilderness Radio ^[4] and costs about \$145.

Figure 1 shows a completed NorCal 40A transceiver. The top view of the transceiver shows the 2.1 MHz variable frequency oscillator (VFO), output power transistor and its associated heat sink. An additional 12 volt power supply and antenna is required to make the transceiver operational. The transceiver includes a double conversion receiver and a transmitter subsection.

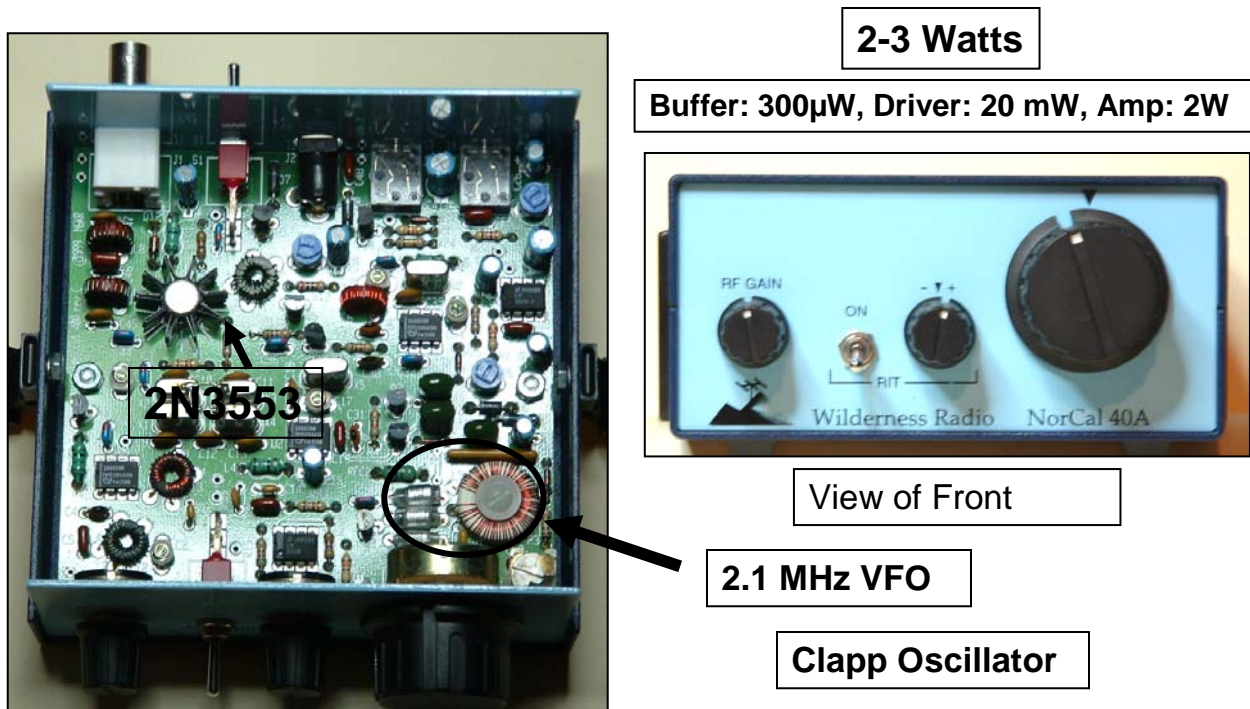


Figure 1: Completed NorCal 40A 7 MHz CW Transceiver

Figure 2 shows a block diagram of the transceiver with the transmitter on the left side and the receiver on the right. The top of the block diagram shows the external dipole antenna and the bidirectional nature of the transceiver. The harmonic filter is common to both the transmitter and the receiver with the direction of flow controlled by an electronic transmit/receive switch (not

shown in this diagram). Doubly-balanced mixer summation frequencies are noted by + signs, and difference frequencies by - signs. The transmit signal is processed through three amplification stages resulting in an output power just over 2 watts.

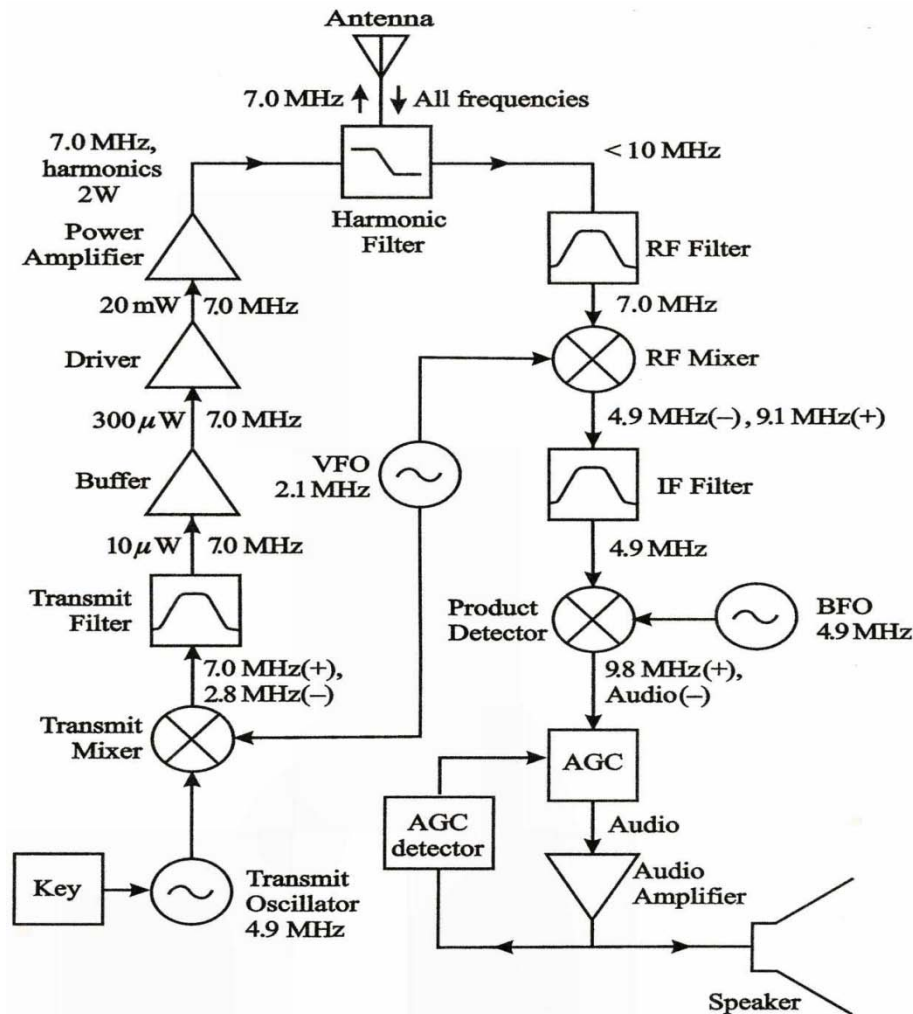


Figure 2: Block Diagram of the NorCal 40A Transceiver

Students enrolled in RF Communications have previously taken a three course sequence in Electronics, a course in Electronic Communications, and a junior level course in Digital Communications. Students taking the lecture portion of the course should have experience in using both MATLAB^[5] and Multisim^[6] software packages. Moreover, the author expects that students enrolled in the laboratory be able to identify through-hole components and properly solder them to a printed circuit board. Also, students should be able to design and construct inductors by placing turns of wire on ferrite toroidal cores^[7]. The Problem Based Learning exercises selected from Professor Rutledge's text and included in RF Communications are outlined in Table 1. The table lists specific Problems and Technical Topics that are designated in the partial schematics^[8] shown in Figures 3 and 4 using a "#" symbol to highlight specific

Problem Based Learning tasks associated with construction and testing phases of the Transceiver Project.

Note from Table 1 that fourteen exercises are presented in the lecture and subsequently implemented in the laboratory over a ten-week quarter. This gives rise to a very ambitious schedule for both the lecture and laboratory. Fortunately, technology in the form of low-cost Vector Network Analyzers is used to streamline some of the laboratory exercises in order to maintain the breadth and the depth of the material in the textbook. The author^[9] presented an ASEE paper in 2009 that covered how “low-cost” Vector Network Analyzers enriched the testing phase and nicely complemented the use of oscilloscopes and function generators in the laboratory.

What is not included in Table 1 are techniques and low-cost equipment used to measure the transceiver’s performance parameters such as noise floor, minimum discernable signal, third-order inter-modulation intercept point, and blocking dynamic range. These topics form the basis of this paper.

Table 1: Problem Based Learning Topics Covered in RF Communications Course

Problems	Technical Topics
7	Parallel-to Serial Conversion
8	Series Resonance
9	Parallel Resonance
13	Harmonic Filter
14	IF Crystal Filter
15	Driver Transformer
16	Tuned Transformer
19	Receiver Switch
20	Transmitter Switch
21	Drive Amplifier
22	Emitter Degeneration
24	Power Amplifier
26	VFO Butler Oscillator
33	Alignment

Technical Approach and Results of Receiver Testing

The American Radio Relay League (ARRL)^[10], founded in 1914, is the national association for Amateur Radio in the USA. Today, with more than 156,000 members, ARRL is the largest organization of radio amateurs in the United States. The ARRL provides a comprehensive list of 16 Receiver tests outlined in their 157 page Test Procedures Manual^[11]. These have been arranged in the ARRL test plan to minimize the required level and frequency of hook-up changes and modifications. Each hook-up, however, is shown complete with all changes from the previous test clearly indicated.

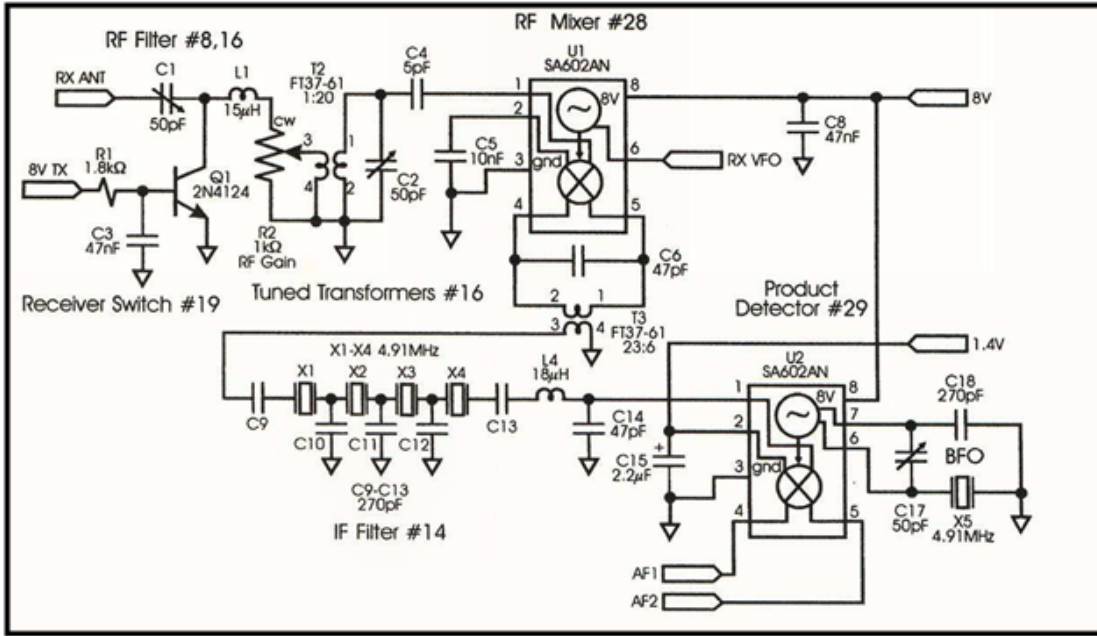


Figure 3: Portion of the NorCal 40A showing Problems #8, #14, #16, #19, and #29

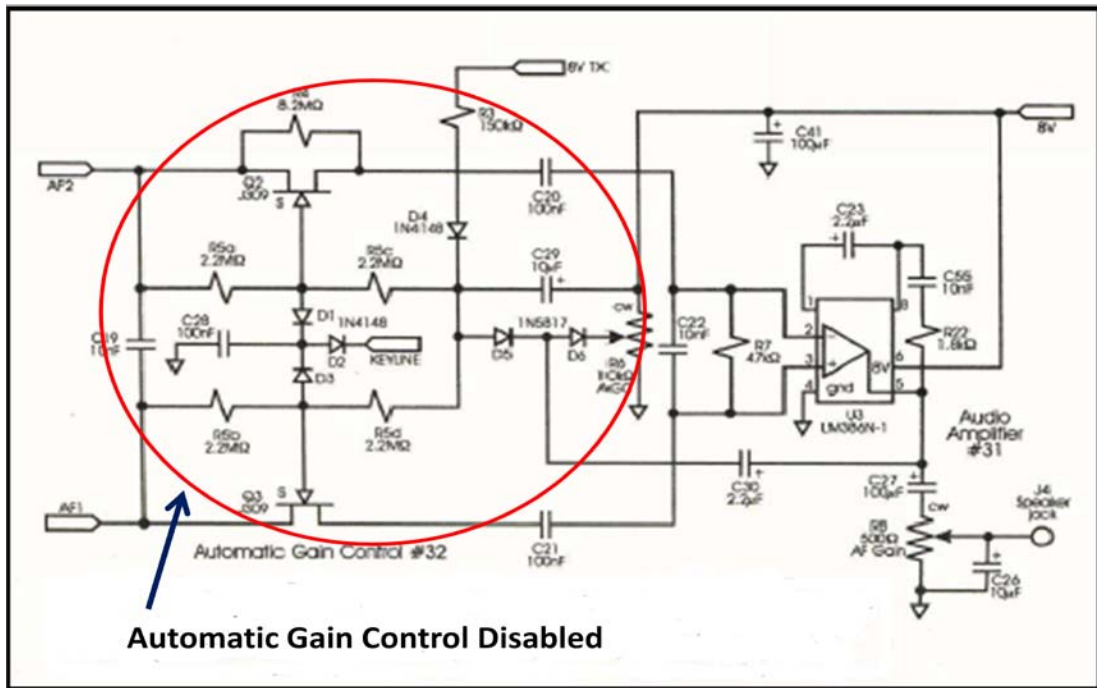


Figure 4: NorCal 40A Schematic showing Problems #31, and #32

A block diagram accompanies each hook-up and any changes from the previous test are shown within a dotted rectangle. This affords the flexibility to easily start anywhere within the ARRL test plan and to perform these tests in any desired order. For this paper only three receiver tests

were conducted. A block diagram accompanies each hook-up and any changes from the previous test are shown within a dotted rectangle. This affords the flexibility to easily start anywhere within the ARRL test plan and to perform these tests in any desired order. For this paper only three receiver tests were conducted.

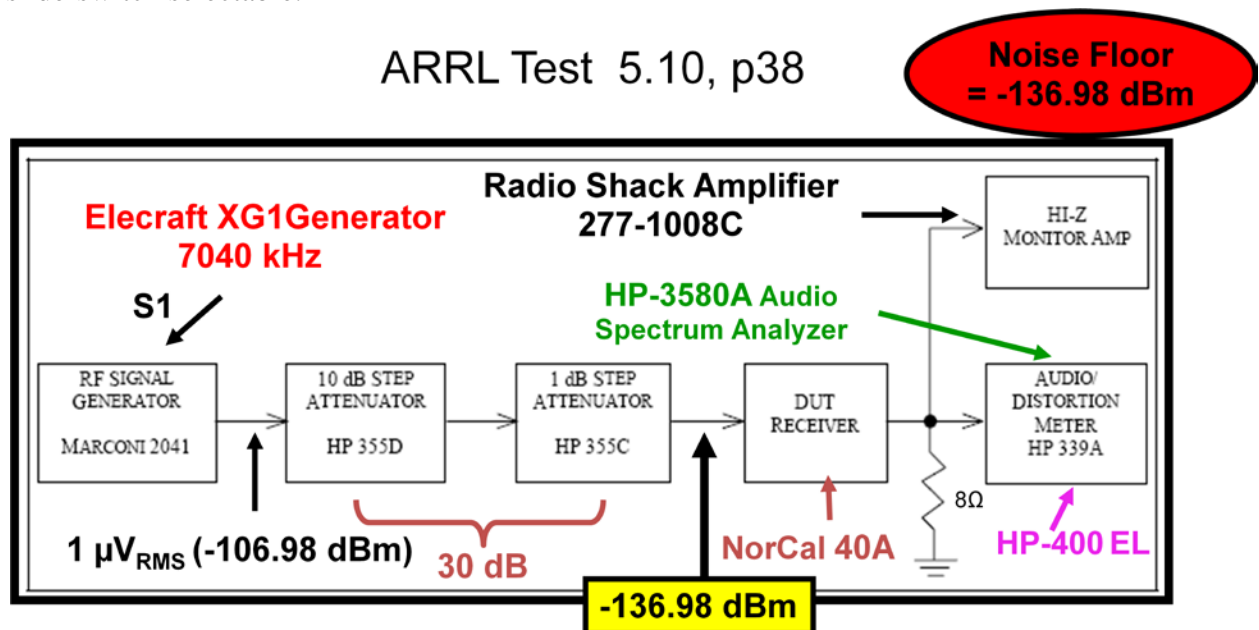
- CW Minimum Discernible Signal (MDS) ARRL Test Procedure 5.10, p38
- In-Band IMD test ARRL Test Procedure 5.15, p76
- Blocking Dynamic Range ARRL Test Procedure 5.70, p53

The sections that follow contain the details of the three receiver performance tests, indicated above, that were relatively easy to conduct with simple low-cost test equipment. The establishment of the receiver noise floor and minimum discernable signal serves as a starting point in evaluating the NorCal 40A receiving system.

CW Minimum Discernible Signal (MDS)

The basic objective of the CW Minimum Discernible Signal (MDS) test is to determine the level of signal input to the receiver that will produce an audio output that is 3dB above the noise floor. The test is conducted with the receiver in the continuous wave (CW) mode using an intermediate frequency (IF) band-pass filter with a 3dB bandwidth of 500 Hz. The NorCal 40A has a four-pole crystal IF filter that satisfies this requirement. For most receiver performance tests the automatic gain control (AGC) will be set to the OFF position, if possible.

Figure 5 describes the ARRL Test Procedure 5.10 for determining receiver noise floor and associated MDS. The test is conducted at 7040 kHz using an Elecraft XG1 signal source^[12]. This is a very low-cost signal generator that produces two RMS outputs of 1μV and 50μV which are slide-switch selectable.



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 Figure 5: NorCal 40A Noise Floor Measurement Test Setup

The Elecraft XG1 has the capability of producing two outputs into a 50 Ω load; namely: S1 (-106.98dBm) and S9 (-73dBm). These signals can be used as calibrated test signals for determining receiver performance metrics. Note the XG1 has replaced the Marconi signal generator indicated in the figure. Other elements of the test fixture are also substituted with low-cost equivalent devices. The test procedure is straightforward, namely: Listen to the signal coming out of the speaker port and subsequently amplified by the Radio Shack Amplifier (277-1008C) ^[13]. Systematically increase external attenuation until the signal is no longer present. To obtain experimental data the author recorded, at each attenuator setting, the output voltage display on the true RMS HP-400 EL ^[14] voltmeter. Figure 6 is a photograph of the MDS equipment used in the test setup.



Figure 6: CW Minimum Discernable Signal Equipment used in Test-Setup

Laboratory data collected over a 90 dB range is recorded in Table 2. The data presented in 5dB increments, but the actual raw data was taken in one dB increments resulting in a receiver noise floor of -136.98dBm with a corresponding voltmeter reading of 2.7mVrms. This value is not displayed in the table.

Table 2: Data for Speaker Voltage versus Input Power in dBm

Receiver Input Signal (dBm)	Speaker Voltage (mV _{rms})
-140	2.4
-135	2.9
-130	4.8
-125	8.3
-120	15.2
-115	24.5
-110	47.5
-105	60.0
-100	114.0
-95	220.0

Note: Receiver Noise Floor is -136.98 and HP 400 EL reading is 2.7mVrms.

Recall that the MDS is defined as the level of signal input to the receiver that will produce an audio output that is 3dB above the noise floor. Thus the voltmeter reading to determine MDS is obtained by multiply 2.7mVrms by $10^{(3\text{dB}/20)}$ or $2.7 \times 1.42537 = 3.814\text{mVrms}$. In practice the multiplying factor is very close to the square root of two = 1.4142 and is frequently used in these calculations. For example, using square-root of two as the multiplying factor yields an RMS voltage of 3.818mVrms.

Linear interpolation via a scientific calculator is the easiest way to compute the value of the MDS. For example, using data from Table 2, namely: (y1=2.9, x1=-135) and (y2=4.8, x2=-130) and inserting $y_{\text{MDS}} = 3.818\text{mVrms}$ yields $\text{MDS} = -132.57\text{dBm}$.

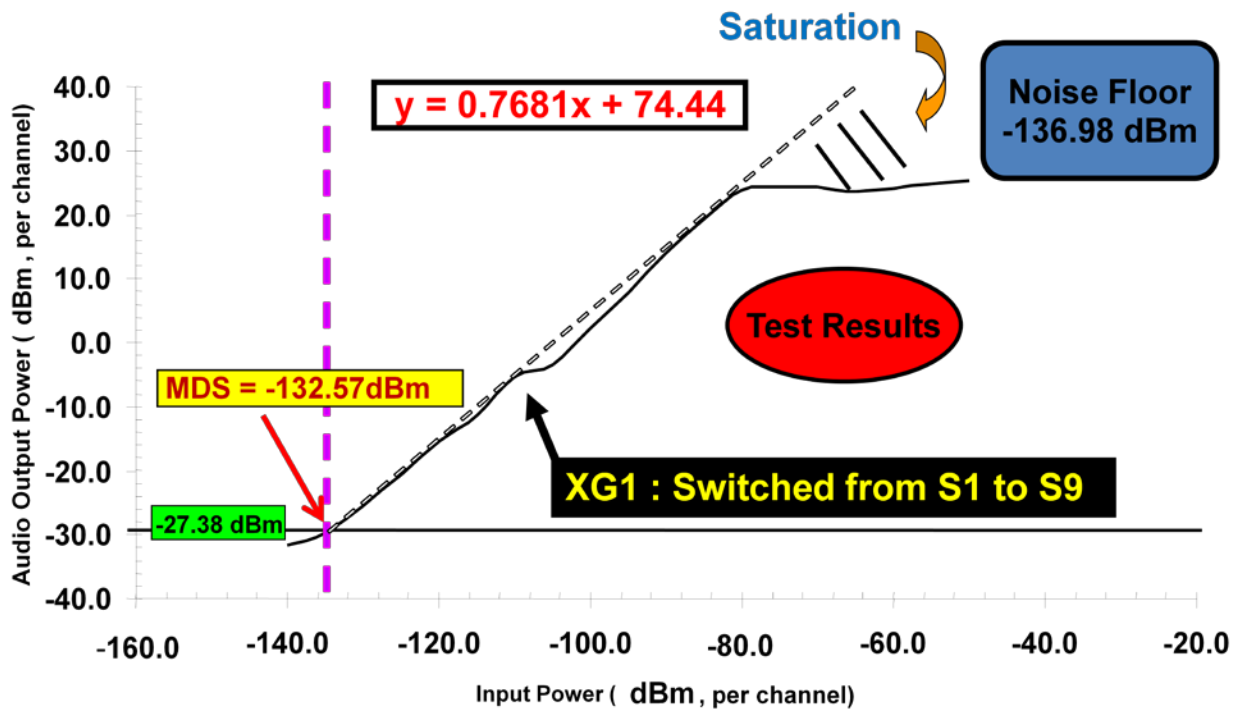


Figure 7: Graphical Summary of Measurement Data and Results for MDS Testing

As a check, the NorCal 40A Assembly Manual ^[15] was consulted and lists, on page 5, a MDS value of -137dBm . Thus our result appears to be consistent with the assembly manual.

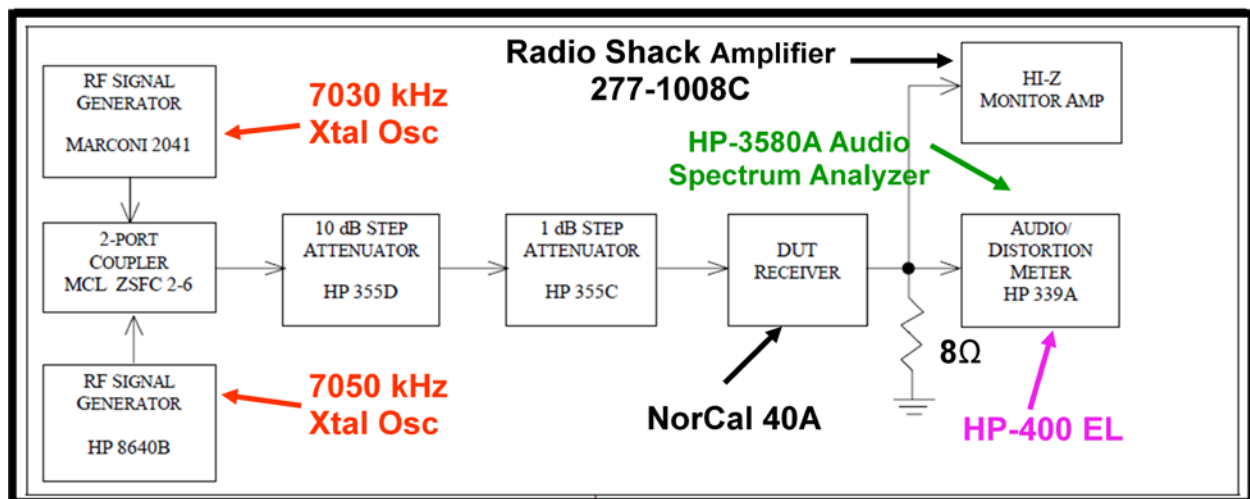
Figure 7 summarizes the calculations for receiver noise floor and MDS. The data from Table 2, when plotted, shows a linear relationship between input and output power levels over a larger range of values until the receiver goes into saturation at -80dBm . Note that the saturation region extends to the right of -80dBm for the data collected. Also notice on the graph that the output to the left of -132.57dBm appears to form a knee in the graph as the receiver noise floor is reached. A best fit straight-line was extracted from the data collected. The slope of this line should be unity as described in most RF Communications textbooks ^[16]. The only explanation that the author has for the slope of 0.7681 is that the input resistance to the receiver is 50Ω whereas the output to the speaker is only 8Ω . Using the normal formula of V^2/R for power calculations may have disrupted the expected value of unity for the slope.

The next section deals with Two-Tone Dynamic Range testing. This is a slightly more sophisticated test and involves to test signals spaced 20 kHz apart. The innovative aspect of this test involves the construction of two Colpitts oscillators. This low-cost signal generator solution works very well and the procedure for conducting the test is described in the next section.

Receiver Two Tone Dynamic Range Test

The purpose of the of the Two-Tone Dynamic Range Test is to determine the range of signals that can be tolerated by the NorCal 40A receiver while producing essentially no undesired spurious responses. To perform the 3rd order test, two signals of equal amplitude and spaced 20 kHz apart and injected into the input of the receiver. The signals are 7030 kHz and 7050 kHz and designated f_1 and f_2 respectively. A block diagram of the ARRL test setup is shown in Figure 8.

ARRL Test 5.15, p76



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Figure 8: CW Two-Tone, 3rd Order Dynamic Range Test Setup

In order to gain additional insight into the purpose of the CW Two-Tone 3rd Order Dynamic Range Test a “mini-review” of some of the underlying concepts is presented. For a smooth transition between review material and actual data collected, the remainder of this section is divided into two parts.

Mini-review of 3rd Inter-modulation Concepts and Test Equipment

The left side of Figure 8 indicates that very high-cost precision signal generators are used to conduct the test. As indicated earlier the author’s low-cost solution for the professional signal generators is to simply substitute a calibrated homebrew crystal oscillators. The remainder of the test setup is the same as that used in the previous test.

The homebrew dual crystal oscillator signal generators were designed by Rumley [17] to work in the 14 MHz range. His rationale for choosing these test frequencies is straightforward. The high frequency (HF) portion of the radio spectrum ranges from about (2.0-30MHz). The HF portion when divided in half yields signals in the Amateur Radio 20 meter (14MHz) shortwave band. For most multi-band transceivers 14 MHz is a good frequency for testing. Unfortunately the NorCal 40A only operates in the 7MHz portion of the radio spectrum. Therefore the frequencies of the oscillator were reduced by a factor of two to 7MHz by scaling the capacitors in the circuit.

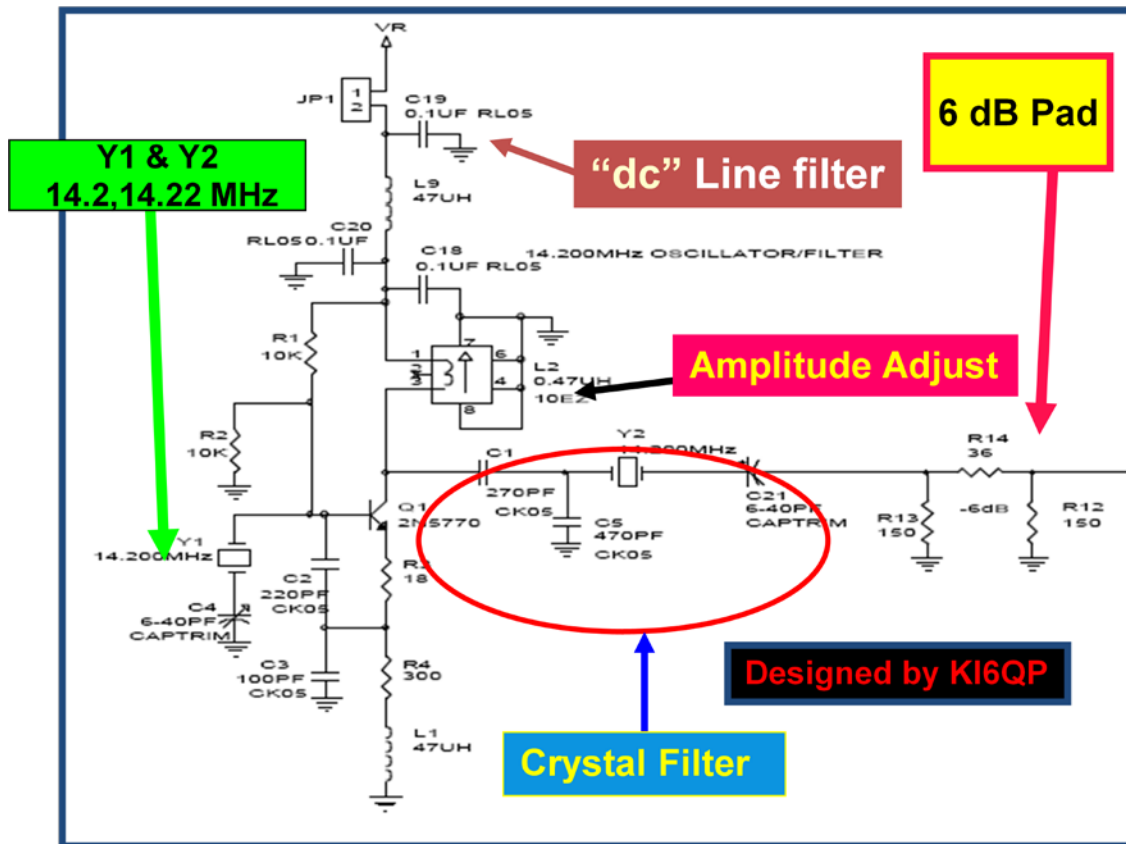


Figure 9: Colpitts Oscillator Schematic for 14.200MHz. Note that 7030 kHz and 7050 kHz Oscillators used in actual test.

Figure 9 is a schematic of one stage of Rumsey's test oscillator circuit. A key feature of this design is the single-crystal filter used to shape the output of the oscillator to a nearly perfect sinusoidal waveform. Also the signal is terminated into a 50Ω 6dB attenuator to control the output impedance.

A photograph of the homebrew low-cost dual sinusoidal signal generators is shown in Figure 10. The circuit is shielded and divided into three sections as shown. The printed circuit board is subsequently placed into an RF tight enclosure in order to reduce interactions between the sections and the external environment.

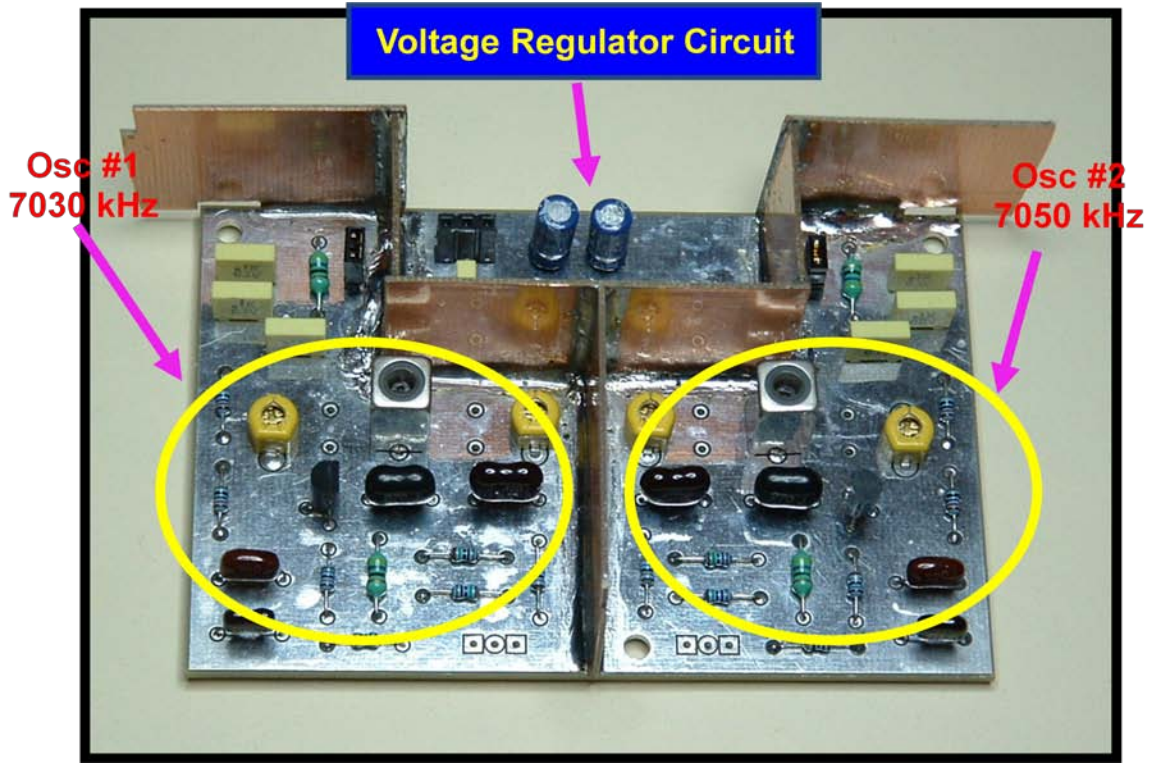


Figure 10: CW Two-Tone signal generator used for, 3rd Order Dynamic Range Testing

The nonlinear characteristics of the two-tone receiver test are presented next, and provide a top level overview as to why the test is significant. The underlying mathematical concept involved in the test is shown in Figure 11. The input from the oscillators consist of combining two signals, namely: 7030 kHz and 7050 kHz respectively spaced 20 kHz apart, as the input test signal to the receiver. The output of the receiver is structured as a polynomial in V_{in} . The first two terms consist of a dc offset term combined with V_{in} . This is called the linear term and represents the desired output of the receiver. However, additional terms consisting of V_{in}^2 and of V_{in}^3 also appear in the output signal. The portion of the output representing the 3rd order term is of most interest in this test. These terms are stated explicitly in Figure 12. Note that the 3rd order products are the signals closest to the fundamental test tones.

To graphically illustrate the receiver output in the frequency domain, a spectrum analyzer sketch is drawn in Figure 13. The closest interfering signals are clearly indicated and are located at 7010 kHz and 7070 kHz.

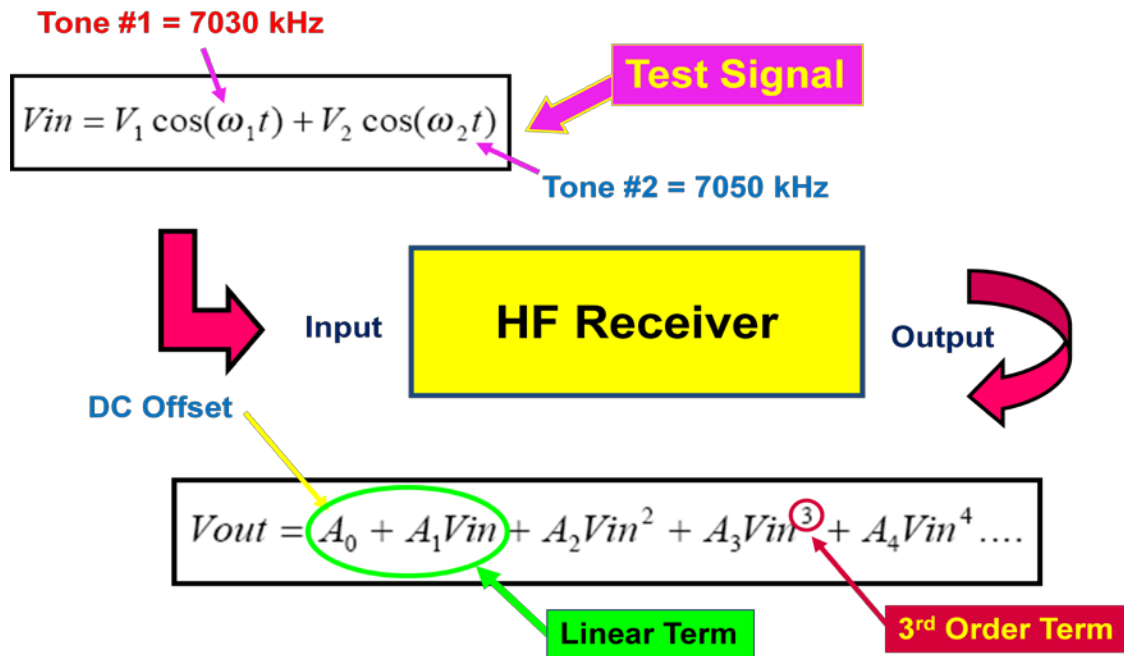


Figure 11: CW Two-Tone, 3rd Order Dynamic Range Test Setup

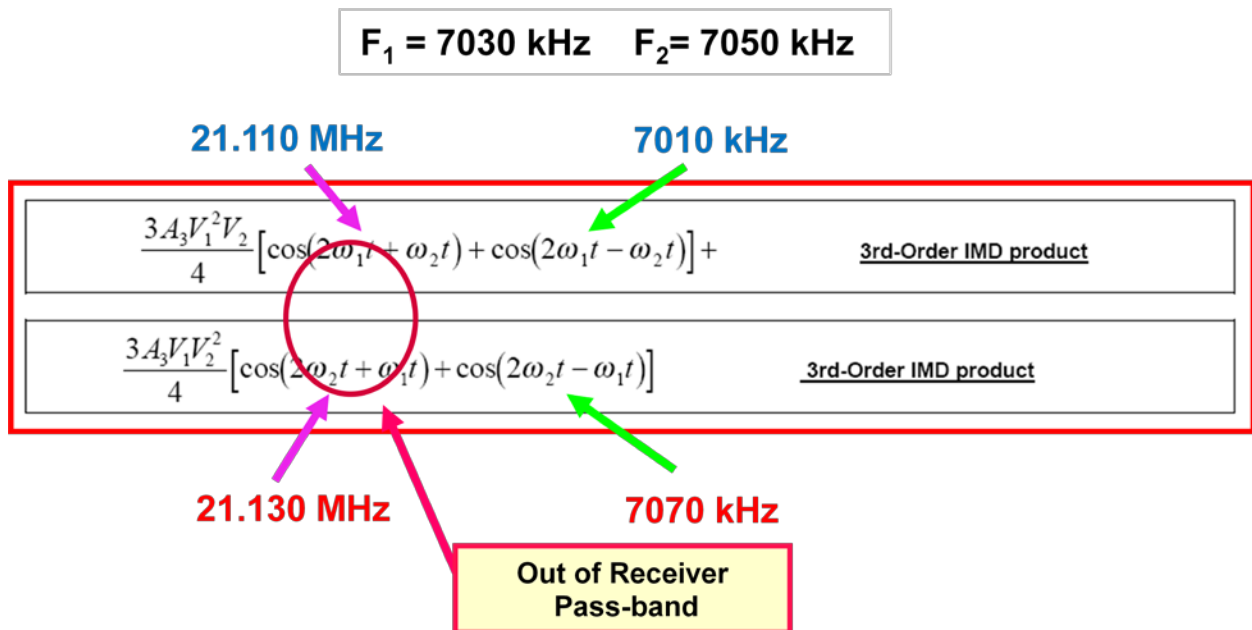


Figure 12: Significant 3rd Order Test Tones Nearest the Fundamental Signals.

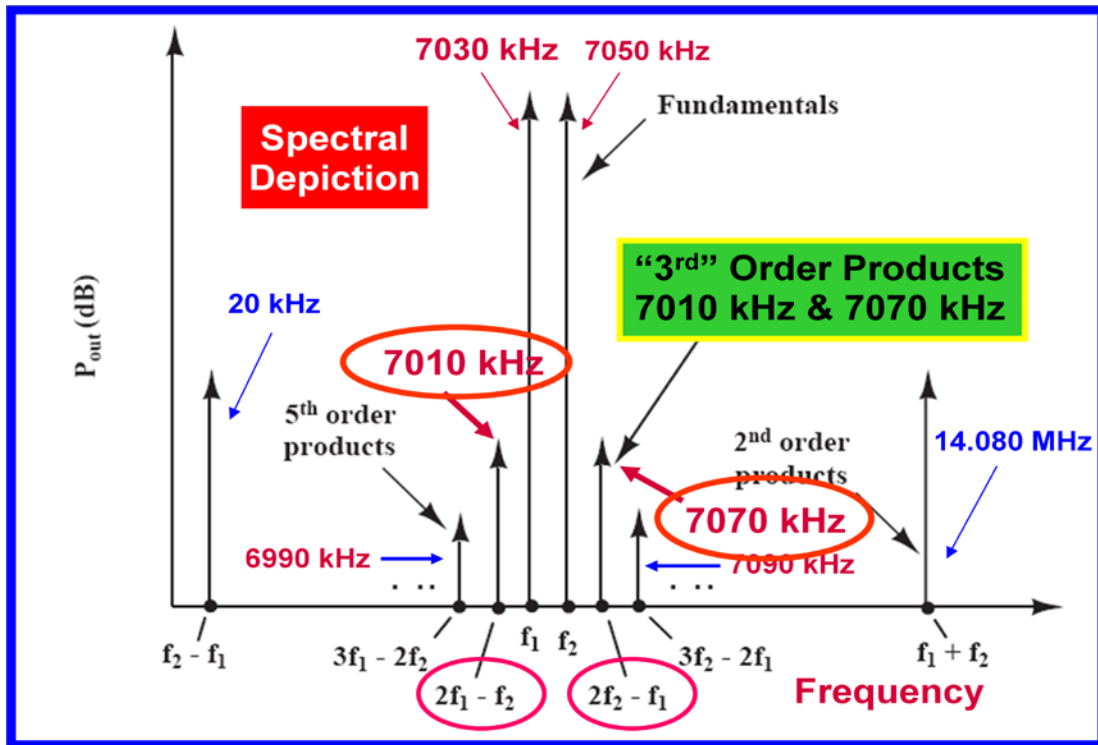


Figure 13: Sketch of the Output Spectrum of Two-Tone, 3rd Order Dynamic Range Test

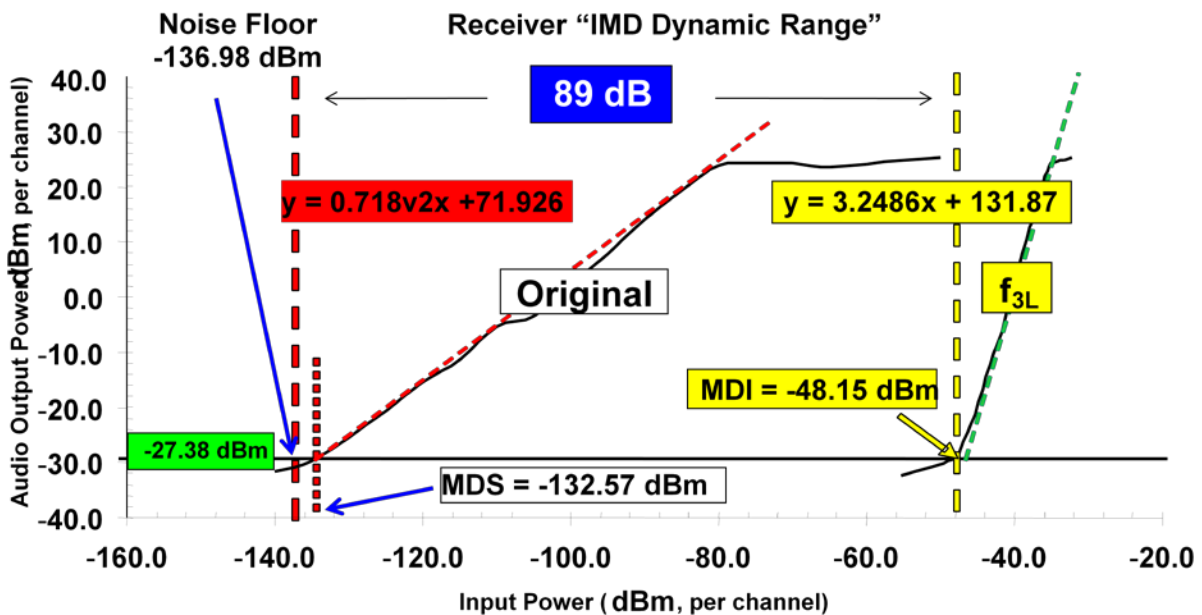


Figure 14: Plot of audio Output versus Input power: $f_{3(low)}$ Inter-modulation Products

Data Collection for Two-Tone Dynamic Range Test

The process of data collection for the test described in Figure 8 starts with rotating the NorCal 40A transceiver tuning knob to the lowest frequency setting around 7000 kHz. As the frequency increases four strong signals will appear in succession, namely: 7010 kHz, 7030 kHz, 7050 kHz, and 7070 kHz. Two of the signals constitute the input test signals, (7030 kHz and 7050 kHz), described in Figure 8. The remaining two signals are the 3rd order inter-modulation products surrounding the test signals as denoted in Figure 13. The signal at 7010 kHz is designated as $f_{3(\text{low})}$ and the one at 7070 kHz as $f_{3(\text{high})}$. The “receiver noise floor” of -55.3dBm is the first data point collected for $f_{3(\text{low})}$.

Table 3: Receiver Input Signal for $f_{3(\text{low})}$ in dBm versus Speaker Voltage

Receiver Input Signal (dBm)	Speaker Voltage (mVrms)
-55.3	2.2
-48.3	3.0
-47.3	3.7
-46.3	5.3
-45.3	7.7

Note: Receiver Noise Floor for $f_{3(\text{low})}$ is -55.3dBm @ 2.2mVrms.

The Minimum Discernable Inter-modulation product (MDI) is defined as the level of signal input to the receiver that will produce an audio output that is 3dB above the noise floor. Thus the voltmeter reading to determine MDI is obtained by multiply 2.2mVrms by $10^{(3\text{dB}/20)}$ or $2.2 * 1.42537 = 3.108\text{mVrms}$. Again, linear interpolation via a scientific calculator is the easiest way to compute the value of the MDI. Using data from Table 3, namely: ($y_1=3.0$, $x_1=-48.3$) and ($y_2=3.7$, $x_2=-47.3$) and inserting $y_{\text{MDI}} = 3.108\text{mVrms}$ yields $\text{MDI} = -48.15\text{dBm}$. A graph of data collected for $f_{3(\text{low})}$ is shown on the right side of Figure 14. The theoretical slope of this line is three whereas the least square curve fit yields 3.24. Differences between input and output impedances are attributed to this difference.

Also note that Figure 14 can be used to calculate the receiver “IMD Dynamic Range” for the NorCal 40A. The previously determined receiver noise floor and the Minimum Discernable Inter-modulation (MDI) values are used for this calculation as indicated in the figure. Mathematically, the difference between MDI and the noise floor is called the receiver “IMD Dynamic Range.” It is a measure of the range of useful signals for the receiver. The dynamic range is easily calculated as:

$$\text{IMD Dynamic Range} = \text{MDI} - \text{Noise Floor}; -48.15\text{dBm} - (-136.98\text{dBm}) = 88.83 \sim 89\text{dB}.$$

Good commercial communication receivers have a dynamic range of 100 dB. Our measure (89dB) is identical to the two-tone dynamic range of 89 dB posted in the front of the NorCal 40A construction manual.

Figure 15 is a theoretical sketch illustrating IP_3 as the 3rd order intercept point. Visually the third-order intercept point, IP_3 , occurs by extending the two straight lines on the graph until they intersect. The value of IP_3 is actually the horizontal axis component of the coordinates describing the intercept point. The value is expression in dBm and serves as a useful figure of merit for communication receiver testing.

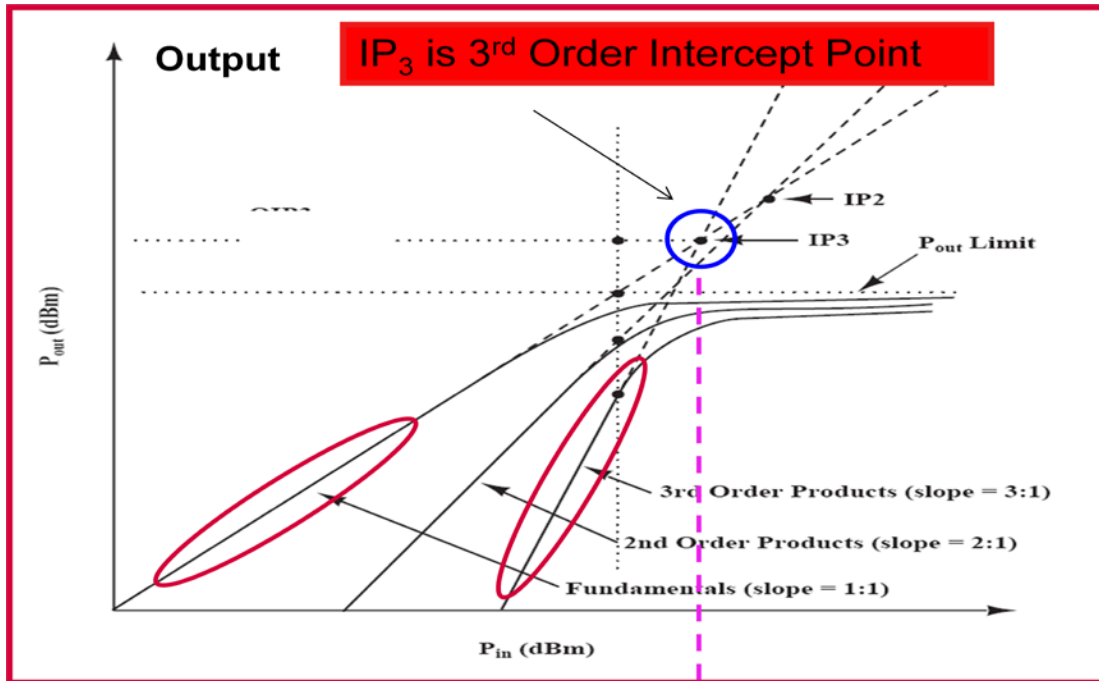


Figure 15: Sketch Illustrating IP_3 as the 3rd Order Intercept Point

Utilizing test results the value of IP_3 is easily computed using the following formula:

$$IP_3 = 1.5 * \text{IMD Dynamic Range} + \text{MDS}; 1.5 * 88.83\text{dB} + (-132.57\text{dBm}) = +0.675\text{dBm}.$$

Other transceivers that can be used to benchmark the NorCal 40A IP_3 performance are the Kenwood TS-830S with an IP_3 of -9.5dBm, and the ICOM 781 with +19dBm^[18]. The better made receivers exhibit a positive IP_3 and values above 20dBm are considered to be excellent IP_3 characteristics.

The ARRL Blocking Gain Compression Test is the subject of the next section and will be the last transceiver performance test discussed in this paper.

Blocking Gain Compression Test

The basic objective of the Blocking Gain Compression Test, also known as the blocking dynamic range test, is to determine the level of gain compression that occurs as a result of another signal present on a nearby frequency. To perform the blocking gain compression test, two signals and a hybrid combiner are required. The signals are spaced 20 kHz apart and injected

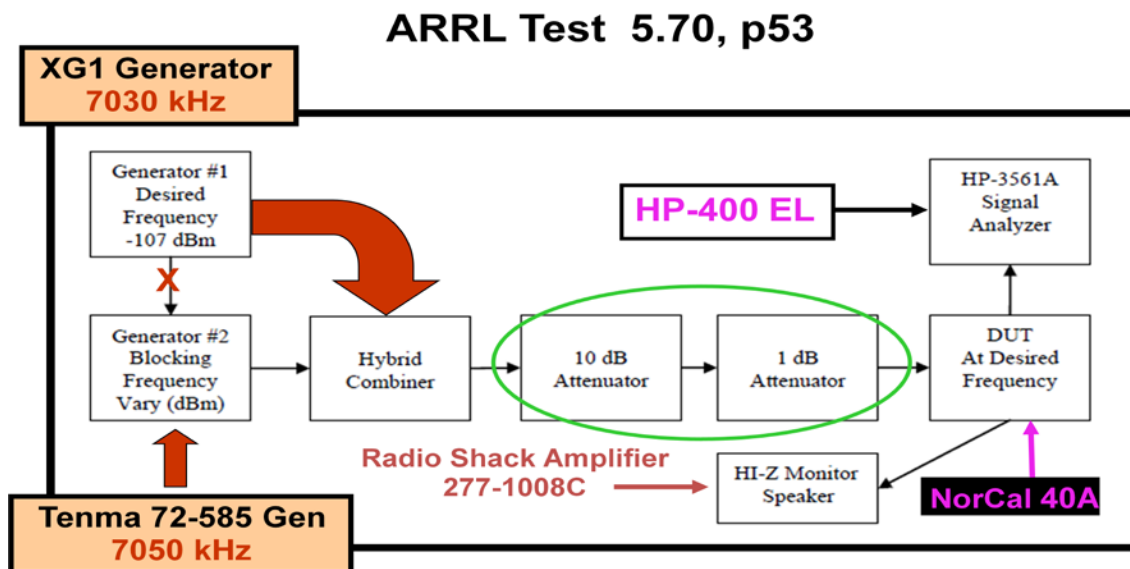
into the input of the receiver. The signals are the outputs of the homebrew crystal oscillator at 7030 kHz and 7050 kHz, respectfully.

A block diagram of the ARRL test set-up is shown in Figure 16. The signal at 7030 kHz is considered to be the desired weak signal. To form this signal the output of an XG1 signal generator (-11.11dBm) is combined with an 88dB attenuator to form a -99.11dBm input signal to the 6dB hybrid combiner. When this signal is passed through a 6dB hybrid combiner the input signal to the NorCal 40A receiver is -105.11dBm. A nominal setting of around -110dBm is the value most often used for establishing a weak signal with test equipment. The NorCal 40A receiver is tuned to 7030kHz and the signal is carefully peaked for maximum response on the HP 400EL voltmeter.

The output of the second generator ^[19] (+0.103dBm) is set to a frequency of 7050 kHz and is considered to be an adjacent frequency interfering signal. The output signal is subsequently increased (attenuator reduced) until the receiver output response at 7030 kHz drops 1.0dB as measured with the HP 400EL true RMS meter attached at speaker output. The required 1 dB compression was obtained with an attenuator setting of 24 dB. Combining the output of second generator and attenuator results in a -23.87dbm signal at the input to the 6 dB hybrid combiner. Passing this signal through the hybrid combiner yields a -29.897dBm blocking level at the input to the receiver. To express the results of this test as a dynamic range, the blocking level is referenced to the receiver noise floor using the following formula:

$$\begin{aligned} \text{Blocking Dynamic Range} &= \text{Receiver Noise Floor} - \text{Blocking Level} \\ &= -136.98\text{dBm} - (-29.897\text{dBm}) = -107.083 \text{ dB.} \end{aligned}$$

This value is normally expressed as an absolute value: 107 dB.



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Figure 16: Block Diagram of Blocking Gain Compression Test

Thus far a fair amount of data has been gathered and Figure 17 is an attempt to explain what the test data numerical values really mean. The horizontal baseline in the figure represents power levels.

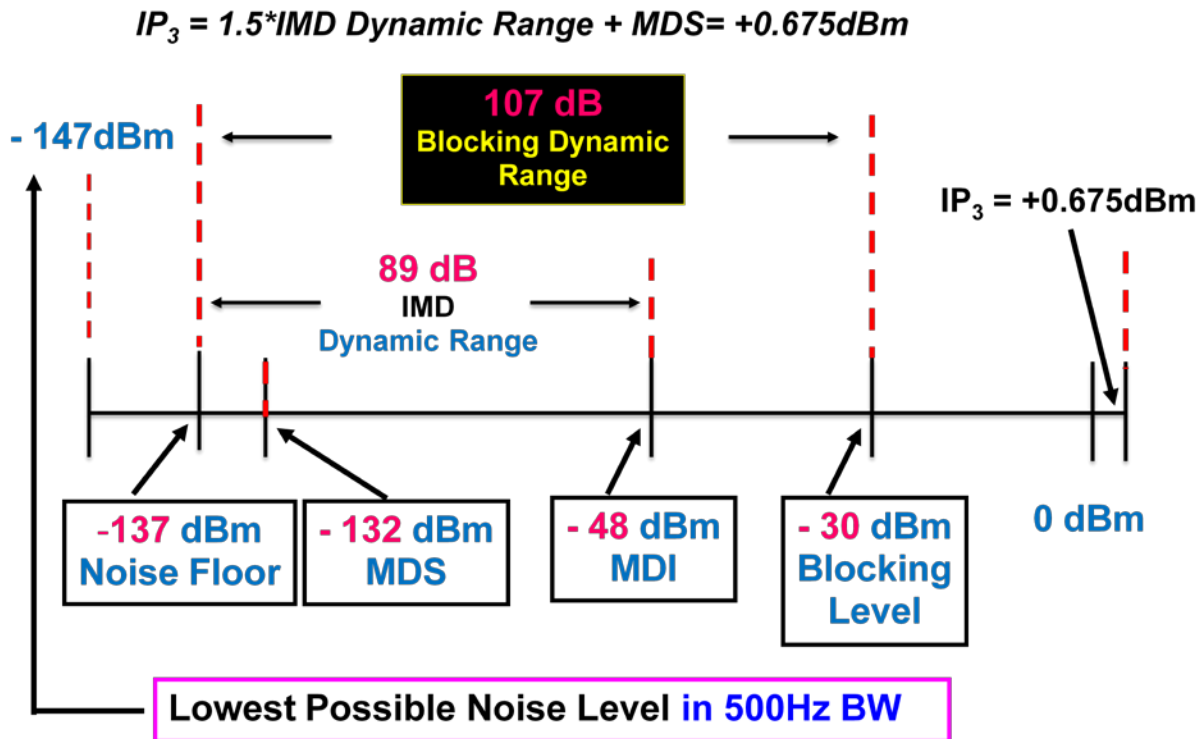


Figure 17: Evaluating the Data Taken in Tests

The left side of figure represents the lowest possible power level which is attributed to receiver thermal noise in a 500Hz bandwidth. Just to the right of 0dBm is the NorCal 40A receiver 3rd order intercept. A positive value of 0.675dBm is very reasonable for a kit-built transceiver.

Some general observations are worth noting. In the figure an MDI level of -48dBm represents the signal level that will begin to create spurious responses. Also shown in the figure is the Blocking Level. This is the level, -30dBm, at which signals will begin to desensitize the receiver. Also note that the IMD Dynamic Range is some 18 dB smaller than the Blocking Dynamic Range. This means that inter-modulation products will be heard long before the receiver begins to desensitize. In fact, they will be heard some 18dB sooner.

The next section introduces the engineering notebook which students are required to maintain during the course.

Engineering Project Notebook

Each student is required to maintain an Engineering Project Notebook ^[20] in the laboratory to record the student's journey through the course with emphasis being placed on recording test data, transceiver construction notes, and final calibration and testing of the transceiver. Many

students also use the notebook as a journal and often record their frustrations as well as their successes. This requirement is well intended but the author has found that most students wait until the last minute to record entries in the notebook. Students today do not have an affinity for paper notebooks. Hence when the course is offered next the author has decided to use Blackboard^[21] as a mechanism for recording student progress in real-time. The laboratory is also used to conduct informal discussion groups which deal with problems encountered during the building and testing phase of the project. The concept of "test as you build" is emphasized in the discussions and students share ideas and problems during group discussions.

In addition, students are grouped in pairs in order to develop a simple "Gantt Chart" to show progress during the building and testing phases. Students are introduced to MS Project^[22] and the actual development and updating of the chart occurs during the laboratory period.

Student Assessment

To date, qualitative and quantitative student feedback on the course structure and project has been very positive and representative selections of student comments are presented in the following student assessments.

The following comments are extracted from course assessment forms developed by the authors. Four questions were presented to the students during the last class. Overall, the author found the comments very encouraging:

1.0 Did the class project illustrate the concepts presented in the course?

“The transceiver project covered just about all of the concepts presented in the course. I was intimidated by all the testing presented in the text. The problems all looked difficult and I was glad we worked the problems in class and then built the circuits in the laboratory. We explored filter design and tested each filter. I liked using the VNA rather than taking data by hand. I really enjoyed making and testing the crystal filter. We developed testing procedures for step-by-step project construction. I was tempted to just put all the parts on the PCB but soon learned to test the circuits after I built them. Performance testing used the ARRL procedure. This was difficult at first until the instructor simplified the procedure”

2.0 Was the class project effective in enhancing your technical skills?

"The project introduced the soldering of many different components onto a printed circuit board, which I had no prior experience with in the past. In addition, this project allowed me to learn about inductors and coils. I always wondered about resonant circuits and was able to gain an understanding as to how they work in a circuit. Also, it was necessary to use a wide range of test equipment to accomplish the tasks outlined in the problems presented in the text. For this course troubleshooting skills were a must. I feel that the project provided an excellent review that spread across concepts which had been

presented in several different courses. It was interesting to see a practical application of all of the concepts that were covered in the course. This was also my first experience in working with RF concepts and I was pleased that my transceiver worked the first time. My transceiver had great performance test results"

3.0 Was the class project rewarding?

"I feel that this class project was very rewarding and I enjoyed seeing the subsystem components coming together to form a complete system. The project walked us through a complete RF system which emulated concepts that I will need in the senior design process, and in addition to the material I learned about RF systems the course provided a review of earlier coursework. I feel that I am well prepared to start senior design next year. I also would have liked to learn about Microsoft Project beyond the simple Gantt chart because I plan to use project management software for senior design."

4.0 Rate this course overall, based on its effectiveness and helpfulness in utilizing your past coursework experiences and preparing you for senior design.

"This course proved to be somewhat demanding but I enjoyed it! Introducing receiver performance testing was one of the high points of the class. Also this was the first large scale project system project that I have encountered, outside a previous Honors project that I completed. One of the nice things about the course is that once it is all said and done you are able to walk away with a completed project that has a certain level of professionalism that cannot be achieved in labs where simple breadboards and jumpers are used. Also, I feel that this course provided a solid foundation troubleshooting that can be taken into Senior Design."

Conclusions

As indicated in the paper the author examined several of the standard tests outlined in the ARRL Performance Test Manual. The introduction of low-cost test equipment gave accurate results for receiver performance testing. In addition, the effort expended in hardware construction and testing offered students an opportunity to gain a "broader technical view" of the radio frequency communication process.

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