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A VHF CRYSTAL OSCILLATOR FOR SATELLITE RECEIVER

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ABSTRACT

This paper will discuss the design of a crystal oscillator used as a local oscillation (LO) for satellite receivers in the VHF band.

INTRODUCTION

There are five types of crystal oscillators. These are as follows: Butler common base. Butler Emitter Follower, Colpitts Harmonic, Pierce Harmonic and the Emitter Coupled Harmonic. Each oscillator has its own advantages and disadvantages. Choosing the proper oscillator for a certain application depends on several factors. Frequency stability, complexity of the circuit, cost, repeatability are among the important factors to be considered.

Only Pierce oscillator will be discussed in this paper. The reader is referred to reference 1 for discussion of other oscillators.

DESIGN CONSIDERATIONS

Pierce crystal oscillator was considered because its short term frequency stability is very good (10-40 ppm above series resonance) with fairly simple circuit topology.

The basic pierce oscillator is shown in Figure 1a. It uses a common emitter amplifier that has an LC tank at the output. The LC is selected so that it is resonant below the oscillation frequency but above the crystal next lower odd harmonic. Both C1 and C2 should be large so that the circuit will give the maximum in-circuit Q and frequency stability. The circuit has good frequency stability because most of the external load of the crystal are mostly capacitive and not resistive.

The local oscillator used on the first prototype of the receiver was designed using phase locked loop technology. Since, the receiver will monitor just two frequencies (137.5 MHz and 137.62 MHz) of the NOAA satellites for the reception of medium resolution data, we decided to use crystal oscillator for its LO (local oscillator). This reduced the overall cost and resulted to a more compact receiver. The frequencies of the LO was set at 116.22 MHz and 116.10 MHz.

The basic pierce oscillator circuit was modified so that two crystals could be used. The oscillator utilizes two crystals, one at 58.05 MHz and the other at 58.11 MHz see Figure 2. These are third overtone crystals. Switching between these two crystals is done by forward biasing the corresponding PIN diodes U3 and U4 which are connected in series with the crystals. The basic phase shift is composed of C13 and C3 and the crystals which looks inductive. These capacitors, as previously stated, should be large enough to swamp out the input and output impedance of the transistor. C16 and C19 couples the crystals to the input of the amplifier Q2, R6, R4, R5, and C8 are used to properly bias the transistor. L11, L6 and R9 are used to bias the PIN diodes. The output tank L9 and C3 is tuned to prevent oscillation at fundamental frequency and attenuate harmonics that are present at the oscillator's output.

The oscillator is buffered using Q1, R8, R11, and R10 are for biasing purposes. C12 couples the oscillator output to the buffer and C20 to be succeeding amplifier. Amplification was done after the buffer circuit to have enough power to drive the multiplier stage. Mini-circuits amplifier was used.

A low pass filter (chebyshev) was used before the multiplier, this attenuates some of the harmonics before multiplication is done. Its cutoff frequency is slightly above 59 MHz.

To reach 116.10 MHz and 116.22 MHz, the output of the crystal oscillator will have to be multiplied. Q3 was bias as a class C amplifier and is used as frequency doubler. C1, C2 and L4 are used to tune the output, R3, R2, C12 and C7 are for biasing the transistor.

The LO must have at least Odbm signal level and spurious of about 35dBc for proper operation of the receiver. To achieve this, a bandpass filter was used to suppress if not eliminate the harmonics at the output of the doubler.

The complete block diagram of the circuit is shown in Figure 1b.

PERFORMANCE

The oscillator has a stability of 10-20 ppm which is typical of the pierce crystal oscillator and is considered as a very good frequency stability.

The output of the oscillator is buffered for isolation purposes. The output of the buffer is shown in Figure 3a and 3b, which gives an output of -2.42 dBm at 58.11 MHz and - 0.91 dBm at 58.05 MHz. The spectrum show relatively high harmonics.

The low pass filter that is connected right after the amplifier was simulated using eesof simulation software. The simulation, see Figure 8a, shows that it would present an insertion loss of about 2dB at 58.11 MHz and 58.05 MHz. The actual measurement using network analyzer Figure 9a, confirms that the simulated result is correct. Lowpass filtering was needed to assure that the harmonics at the input to the multiplier is minimized. The output of the low pass filter shows that harmonics were attenuated as indicated in Figures 4a and 4b.

Some harmonics and the fundamental frequency will still be present at the output of the doubler as shown in Figures 5a and 5b. Filtering is still needed at the output of the multiplier to attenuate the harmonics at the desired level, in this case, a bandpass filter was used. This filter was also simulated, see Figure 8b. This gave an insertion loss of about 9 to 12 dB, this was so because of the difficulty of finding the exact value for these components. The value of the components that were used are slightly different from the original values. The actual measurement of the output of the band pass filter in Figure 9b, also shows that the simulated result is correct. The actual output spectrum of the local oscillator at the band pass filter in Figures 6a and 6b, show lower spurious. Figures 7a and 7b show the output of the local oscillator having low phase noise at a span of 100khz.

IMPROVEMENTS

Higher frequency could be attained by properly selecting the value of the tank circuit at the frequency doubler. Frequencies in the range of 450 MHz were achieved by changing the value of the inductor of the tank circuit to 2.5nH (Coilcraft A01T). This could be further increased by using multiplier utilizing step recovery diodes after the doubler.

Component characterization is suggested to ensure that the values that are being used are correct, specially for the values of the bandpass filter at the output of the LO. By doing this, the insertion loss of the bandpass filter will improve. If exact values were used, the filter would have 0.5 to 1 dB insertion loss. This indicates that the values of components for the output filter is critical.

REFERENCES

1. Matthys, Robert J. (1987). Survey of VHF Crystal Oscillator Circuits. Proceedings RF Technology Expo 87, February 11-13, 1987, pp. 371-381.

2. Matthys, Robert J. (1990). High Performance VHF Crystal Oscillator Circuit. Oscillator Design Handbook, A Collection from RF Design, pp. 38-41.

3. Troctschel, Bill (1990). K6UQH, UHF/Microwave Oscillator, The ARRL UHF/Microwave Experimenters Manual.

4. Sabin, William E. and Edgar O. Schoenike (1987). Single Sideband Systems & Circuits, pp. 354-367.

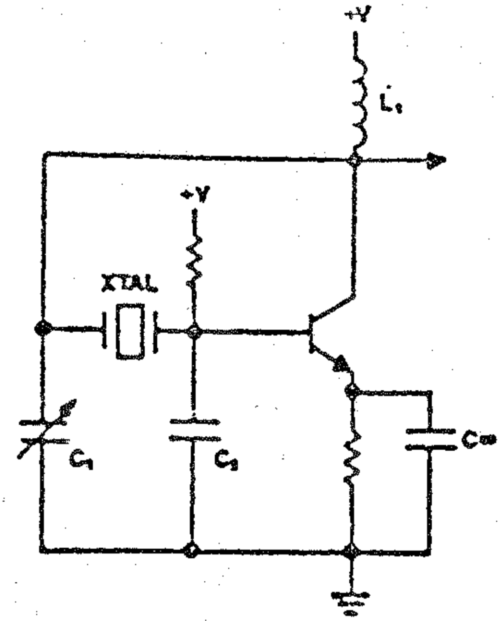

Figure 1a. Harmonic Pierce. Has a good to very good frequency stability. It operates at 10-40 ppm above series resonance.

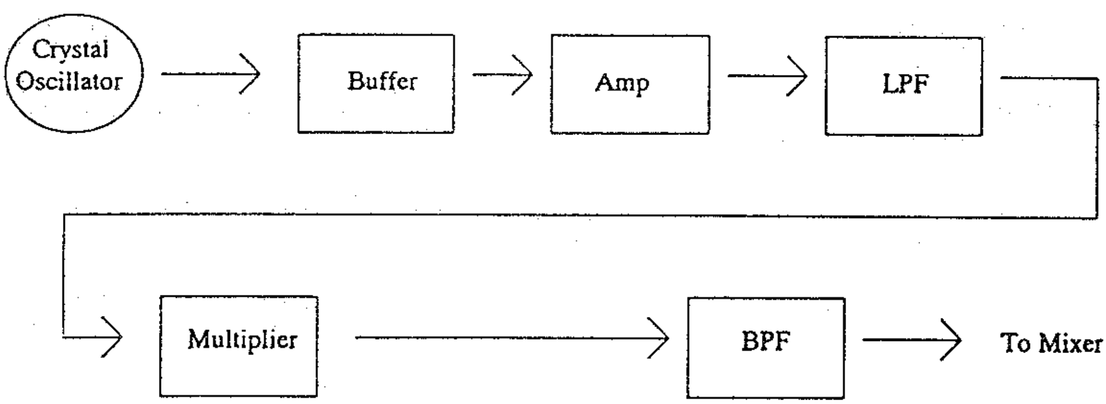

Figure 1b. Block Diagram of the Local Oscillator

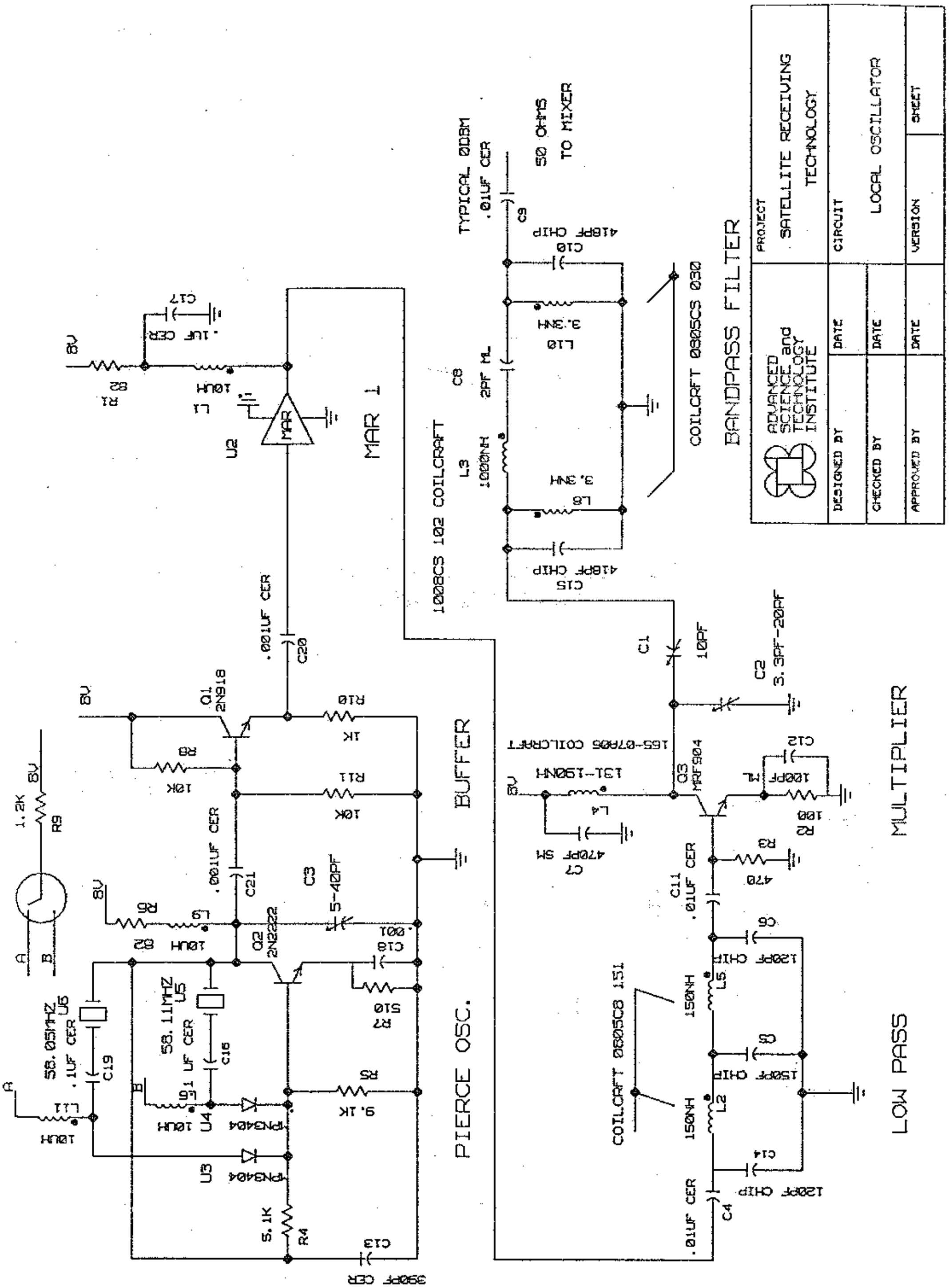

Figure 2. Complete Schematic Diagram of the Local Oscillator

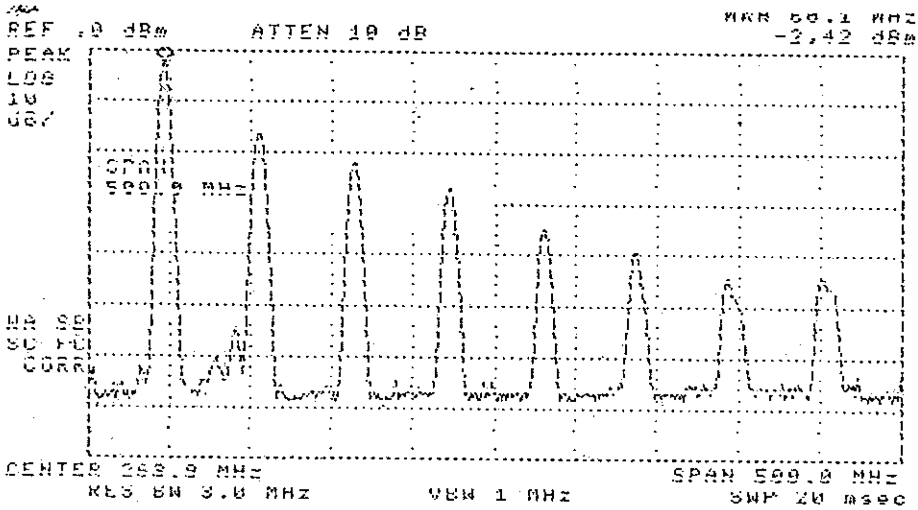

Figure 3a. Buffered Output of the Crystal Oscillator Using 58.11 MHz Crystal

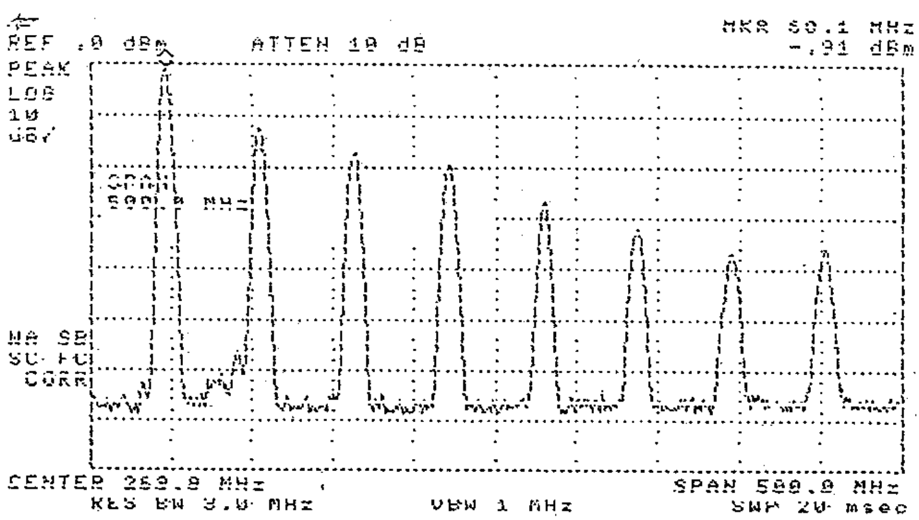

Figure 3b. Buffered Output of the Crystal Oscillator Using 58.05 MHz Crystal

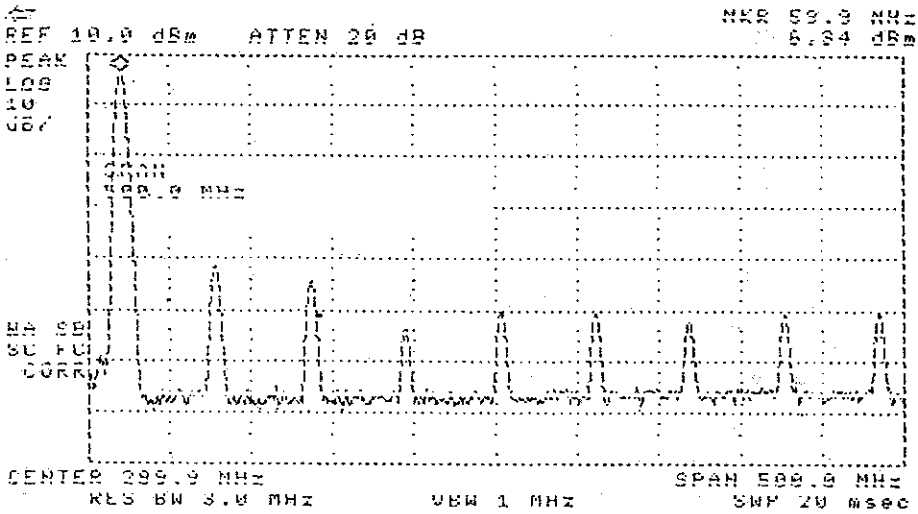

Figure 4a. 58.11 MHz Output of the Low Pass Filter with Attenuated Harmonics

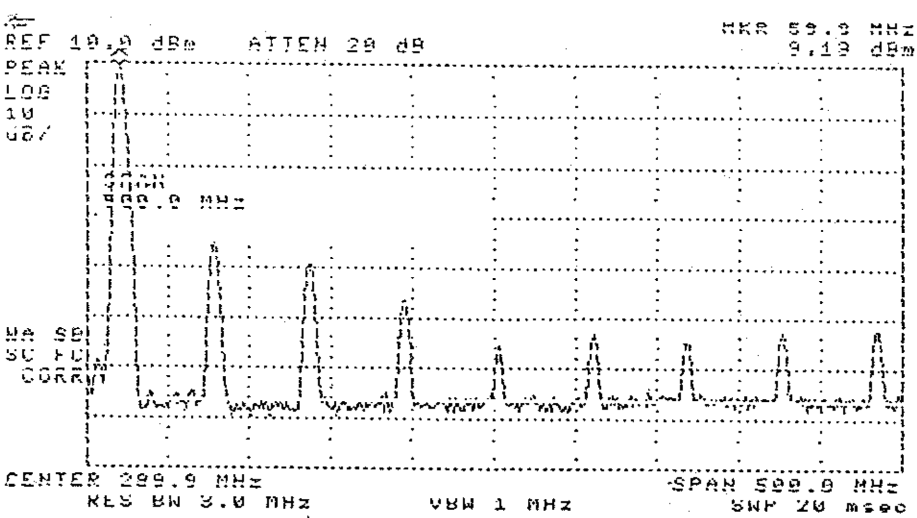

Figure 4b. 58.05 MHz Output of the Low Pass Filter with Attenuated Harmonics

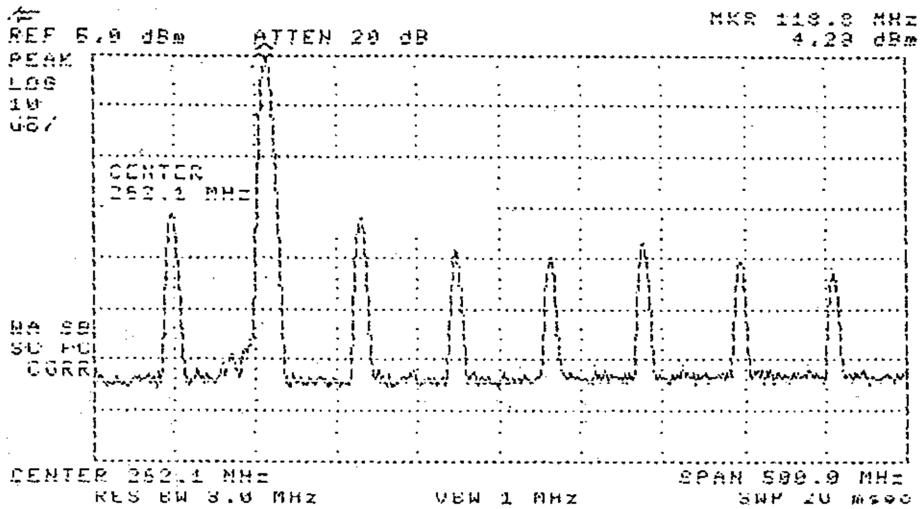

Figure 5a. Multiplied Output of 58.11 MHz

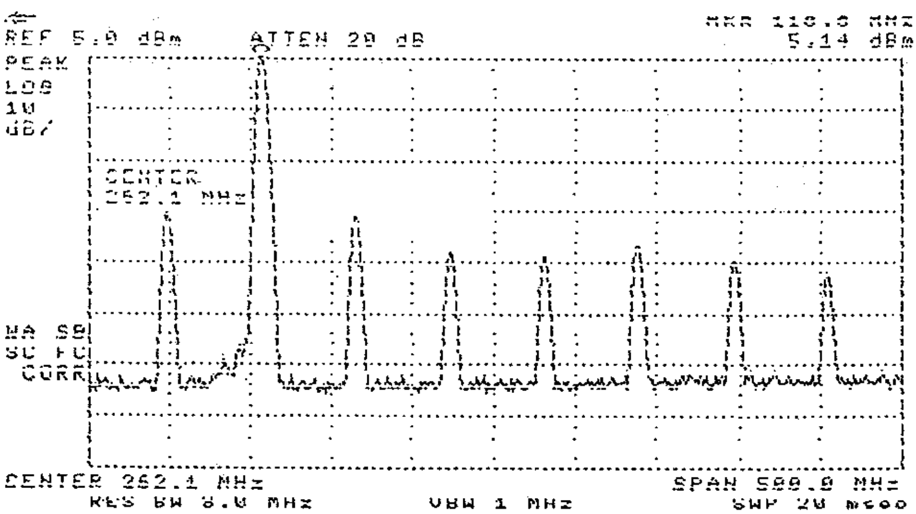

Figure 5b. Multiplied Output of 58.05 MHz

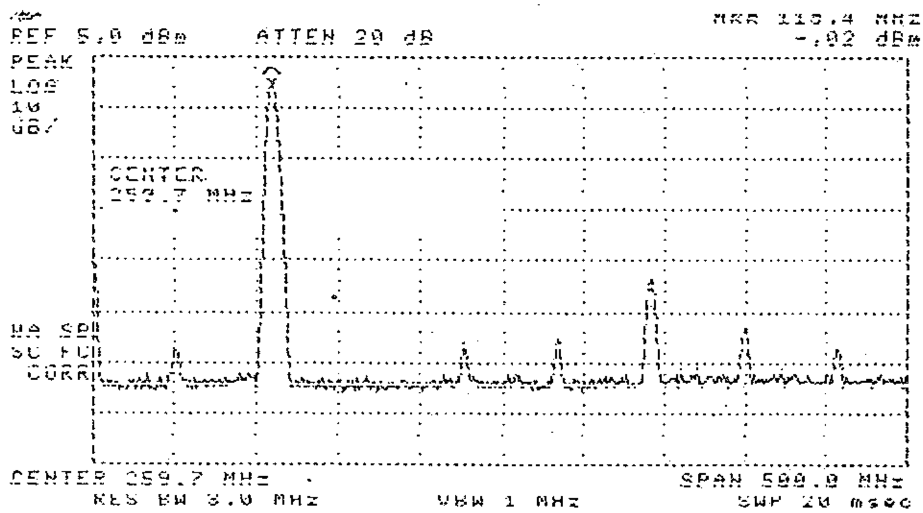

Figure 6a. Output of the Band Pass Filter at 116.22 MHz with Low Spurious

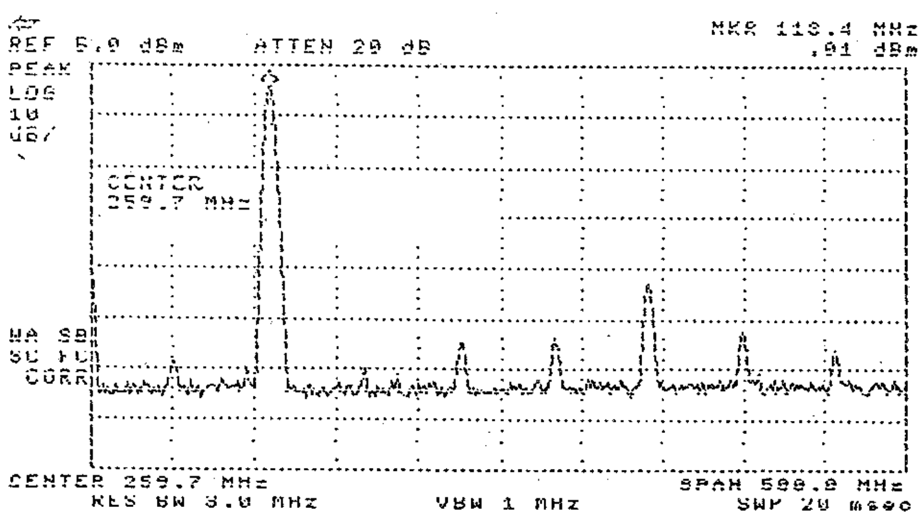

Figure 6b. Output of the Band Pass Filter at 116.10 MHz with Low Spurious

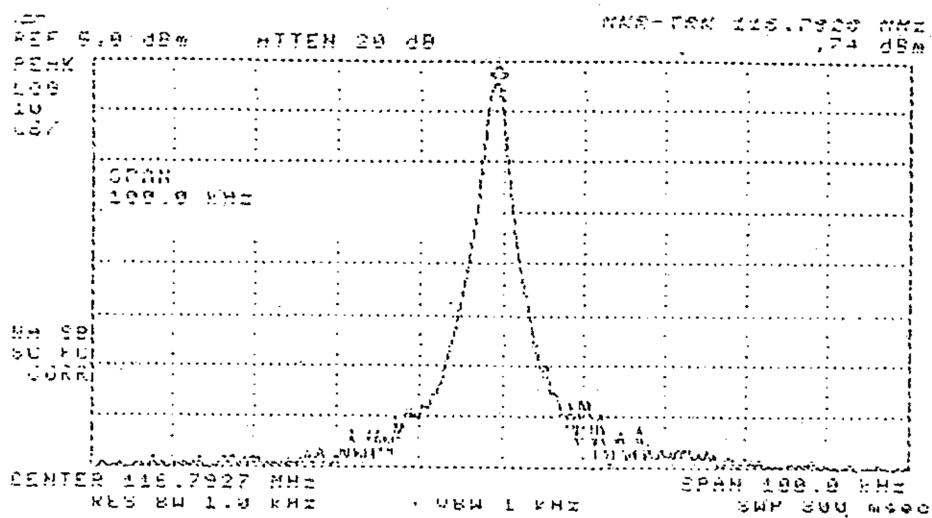

Figure 7a. 116.22 MHz Output Showing Low Phase Noise at a Span of 100 KHz

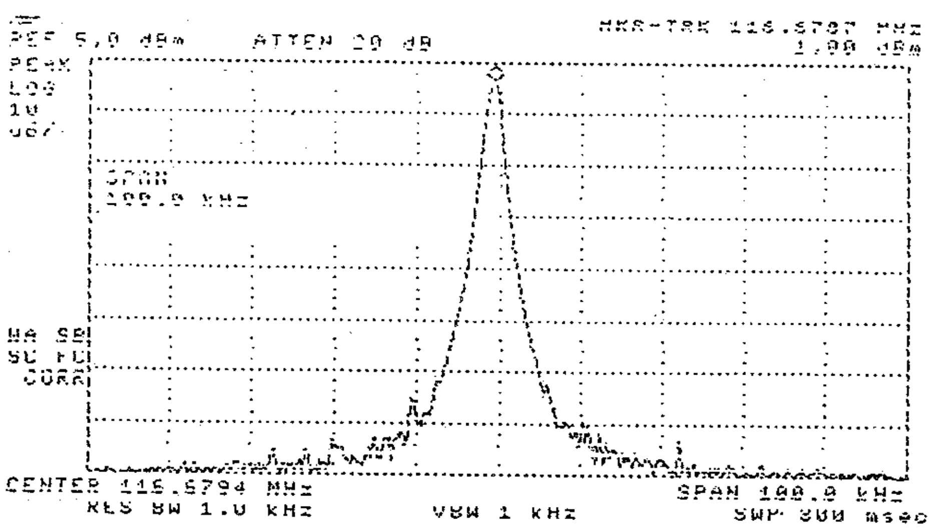

Figure 7b. 116.10 MHz Output Showing Low Phase Noise at a Span of 100 KHz

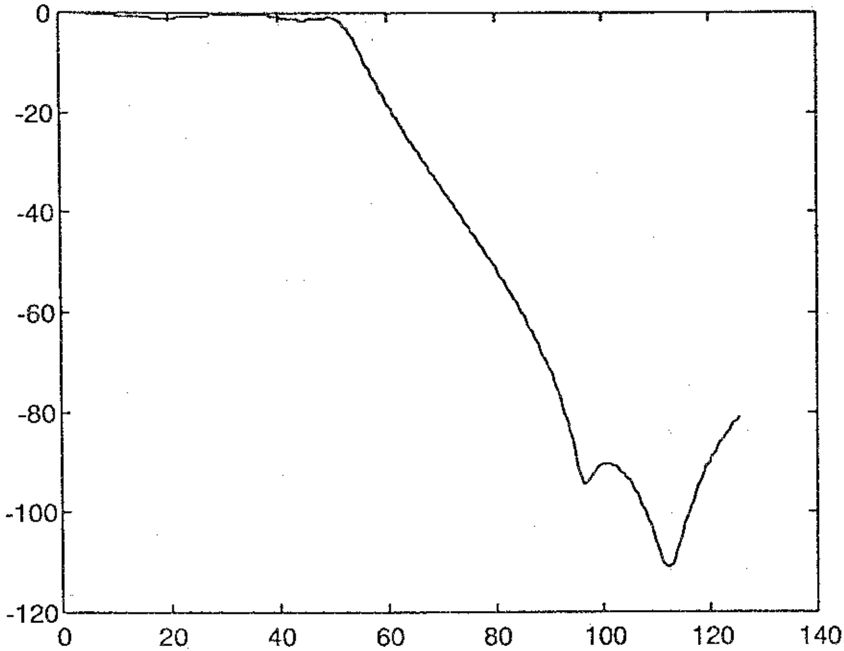

Figure 8a. Simulated Low Pass Filter Response Showing 2dB insertion Loss at 58.05 MHz and 58.11 MHz

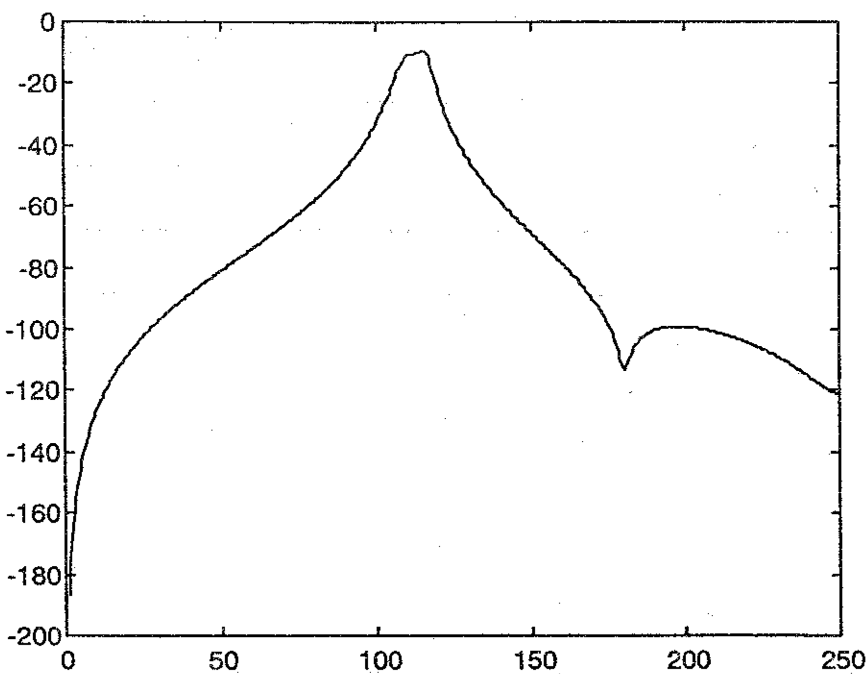

Figure 8b. Simulated Band Pass Filter Response Showing 10 to 12 dB insertion Loss at 116.1 MHz and 116.22 MHz

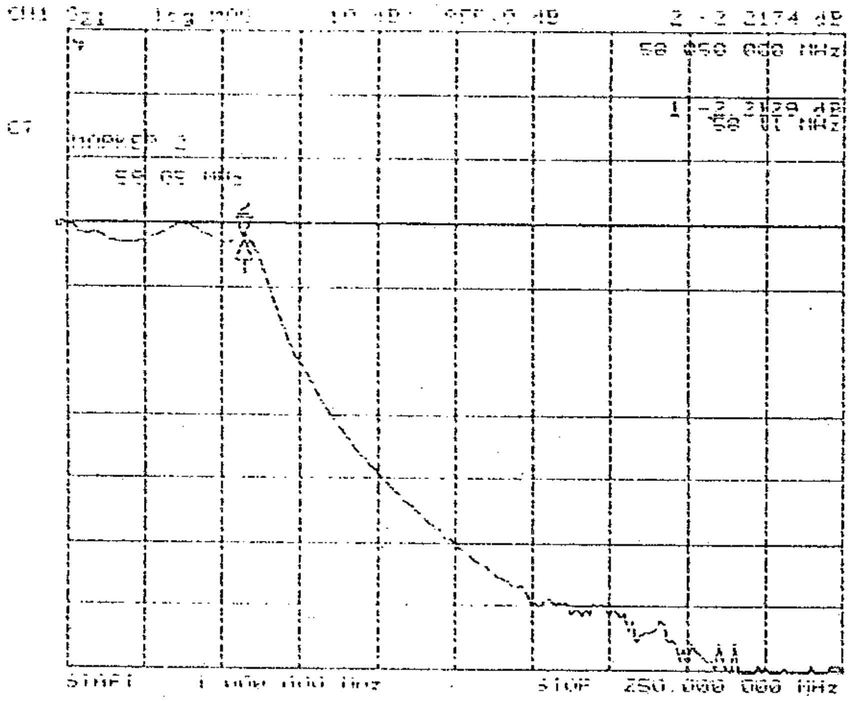

Figure 9a. Showing the Actual Response of the Low Pass Filter, Using Network Analyzer.

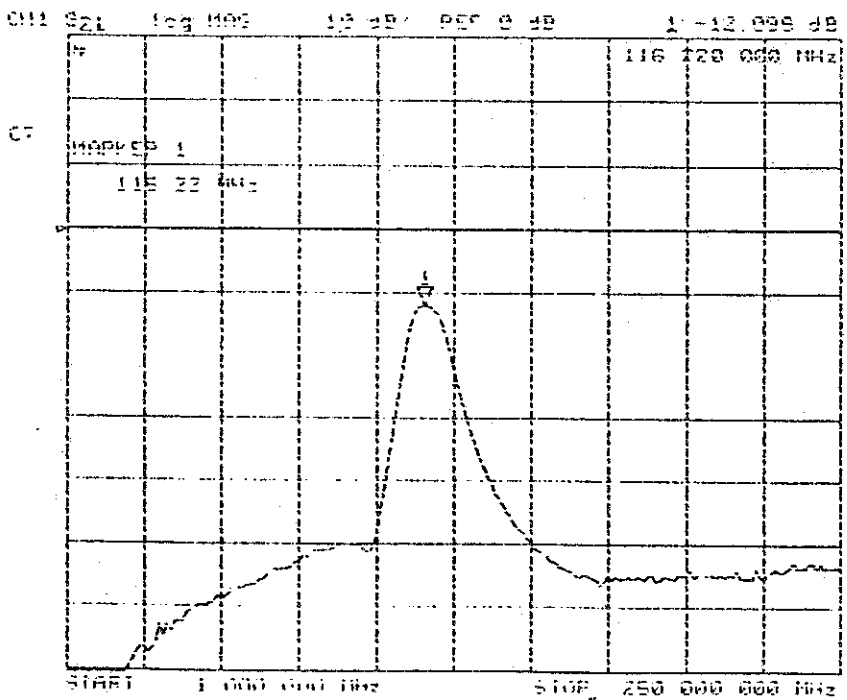

Figure 9b. Showing the Actual Response of the Band Pass Filter Using Network Analyzer