Some Thoughts on Design of the 40M Transceiver

Earlier in this article, I promised to write about the design of our transceiver project but deferred that discussion in order to let you start building. Now it's time to begin, so let's take a look at how we translate our objectives into an actual transceiver.

When starting a design for any piece of equipment, it is typical to identify the types of stages being used (the configuration) and then consider the specific characteristics needed for each stage in order to achieve the overall performance desired. Generally, there are only a few configurations in current use, with variations. In this case, we will make our transceiver a bit more straight forward by making it a separate receiver and transmitter with a common frequency determining circuit in the form of a variable frequency oscillator. Selectivity will be driven by a simple crystal filter. We will omit several optional features in this transceiver in order to keep the project simple. However, they can easily be added later on.

Take a look at the boxes in Figure 1of the published article to see the configuration of our project, especially the stages used in the receiver, and notice how the various stages fit together. The need for most of the stages will be easy to determine. If not, you might want to review the discussion on receivers in the ARRL Handbook or some similar text. The major driving factor in determining the characteristics of each stage in our configuration is the gain distribution throughout a piece of equipment, regardless whether it is a receiver or transmitter, for this establishes the overall performance. In our case, we want to hear any signal that is significantly above the noise at the receiver input. For 40M, the noise levels are easily 30 to 40 dB above atmospheric noise and can easily be higher in some environments. For a CW signal that is 6 dB above the noise, that translates to input levels of - 100 to-110 dBm in a 500 Hz bandwidth. We will want to transform this signal into an audio waveform at a level of about -17 dBm, assuming a 16 ohm set of headphones. (This last figure is based on a recent discussion from the EMRFD reflector on Yahoo.com and reflects the amount of power necessary to produce a comfortably loud signal in the headphones.) Thus we need an overall receiver gain of about 83 to 93 dB. At the end of the receiver discussion, I will show how this overall gain was achieved. Transmitter gain depends only on the power available from our chosen master oscillator and the final output level required, in our case five watts.

The receiver case is more complex than a transmitter as the receiver must take into account many factors associated with the input signal. There are weak signals, strong signals, atmospheric noise pulses, man-made noise and interference, signals that are very close spaced and even harmonic signals. The receiver has the daunting task of separating weak signals in the presence of strong signals and amplifying the weak signals while trying to minimize the noise coming along for the ride. It must do this in a fashion so that with a modest amount of hardware, that the signal from afar can be copied. Internally, the gain distribution plays an important role so that the receiver itself does not distort the signal and that the gain of each stage is set to optimize the performance of that stage so the resultant summed output is a true representation of the original signal. A good example to demonstrate this is a front end RF amplifier ahead of a mixer stage. If the RF amp has too much gain it will overwhelm the mixer and it is downhill from that point forward. Too much RF amplifier gain will not only amplify the signal you want to copy but the noise as well will be amplified. Noise and interference also requires that most of the receiver gain be obtained downstream from the device which provides signal selectivity, in our case a crystal filter. No point in amplifying signals that will eventually be thrown away, is there? Besides, large interfering signals can lead to distortion and non-linearities in the receiver.

As a general rule, it is also a good idea not to place too much gain in a single stage. W7ZOI in the seminal Solid State Design for the Radio Amateur speaks to having a reasonable gain per stage to enhance overall stability. Placing too much gain in an individual stage as a means of reducing the number of components can be equivalent to a time bomb waiting to explode.

Often, the design of a stage is also modified by the designer's previous experience. This transceiver is no exception. For instance, the mixer, IF amplifier, product detector/carrier oscillator and audio amplifier were all selected because they were solid circuits that have worked many times before in my previous projects. The circuits are straightforward and rarely cause any unexpected problems such as unwanted oscillation. The parts are also widely available and usually very inexpensive. As you gain experience, you will probably also collect a "stable" of tried and true circuitry for your future projects. The beauty of having this collection is that you can concentrate your experimentation on a specific area, such as a crystal filter, without worrying whether the overall equipment is likely to be successful.

A few stages will require some individual considerations, which we will discuss here.

The question of whether to include a receiving RF amplifier in a 40M transceiver is probably one of the most frequent discussions among homebrewers. I included it as an option. The deciding factor is the external noise level, which generally decreases with frequency. As a rule of thumb, signals above say 20M most likely would benefit from a measure of RF amplification. At 40M, the desirability of such amplification is "iffy". If included, the amplifier may even reduce strong signal handling capability without adding weak signal sensitivity. For sure, there will be enough gain without the amplifier to provide a reasonable number of contacts. And if you find that the noise level increases in your receiver when you connect an external antenna, then you probably don't need the optional amplifier. The only other reason for adding the amplifier might be if you suffer from having some hearing loss. If this is the case, then strictly speaking you should add gain after the crystal filter. But, the optional RF amplifier may be an easier implementation. My hearing is not what it was back in 1950 when I would listen for the weak signals on my trusty crystal set. So, I found the amplifier to be a welcome addition. If you do add the amplifier, then from the TR switch to the amplifier output there is a gain of 10 to 20 dB.

Next is the receiver mixer. I chose a double balanced diode mixer as it is straightforward, robust in the face of strong signals, and easily implemented. You can use a commercial unit or make one yourself. The commercial unit is foolproof but much is to be learned from making your own mixer. Both designs are included here.

Now let's digress from talking about gain for a moment and consider the frequency determining circuitry. I chose a Variable Frequency Crystal Oscillator (VXO). The major advantage over a non-crystal controlled oscillator is stability and ease of construction. That's especially important in a transceiver to be constructed by a beginner. The tradeoff is reduced frequency range. However, we can use multiple crystals in parallel (usually called a super VXO and invented in 1980 by JA0FAS and JH1FCZ) to extend the range somewhat. The tradeoff of limited frequency range is not too awful in this case because we can choose a range (7.015 to 7.040 MHz) that includes the new and old 40M QRP frequencies and lots of other heavily used frequencies which provide plenty of action and available signals. So it is almost like having the best of all worlds, moveable but stable.

You may wonder why the particular frequencies used for the VXO were chosen. In this case, the answer is easy. The VXO frequency, which also determines the IF used, was chosen because it allows use of readily available, low cost crystals (36 cents each) in the VXO, the crystal filter in the IF and in the product detector. These crystals are ground to produce standard frequencies used in large quantities of digital circuitry and other timing circuitry. Of course, it is also necessary to find a set of frequencies that don't result in bad combinations producing spurious signals at the IF frequency. Production of these spurious signals and how the choice of LO and IF frequencies affects their production is a rather involved topic that is probably best explained in a text like the ARRL Handbook or EMRFD.

Following the mixer is the post mixer amplifier and 6dB pad] The pad is included to reduce impedance variations with signal level ahead of the crystal filter. The amplifier offsets losses incurred earlier and isolates the mixer. It is important that this amplifier be able to handle strong signals since it occurs before any selectivity in the receiver. Using a transistor operating with higher current generally satisfies this requirement.

Next is the crystal filter, chosen to be a Cohn type for simplicity of construction. The number of crystals used is a tradeoff between selectivity and ease of construction. All crystals used must lie in a frequency band between 50 and 100 Hz of each other when placed in a test oscillator. Typically, a set of ten crystals purchased as a lot will have at least four crystals within the proper range. If not then a three crystal filter could be constructed and should still have good enough selectivity for a reasonable number of contacts.

Following the Crystal Filter is a two stage Hybrid Cascode IF amplifier as described in the December 2007 QST article by W7ZOI and WA7MLH [2]. This article is available on the Internet. As usual with these two authors, there is much detail from a basic circuit all the way to a three stage IF amp complete with an AGC (Automatic Gain Control) circuit. The article discusses the possibility of only a two-stage circuit, which I opted for. With two stages, a 35 to 40 dB gain is possible and it adds the possibility of adding AGC at some later time. I modified the circuit to include a manual gain control and to also enable monitoring the transmitted signal. This is a way to have a sidetone by monitoring the transmitted signal. In an email to WA7MLH, I inquired about using two stages versus three and he concurred that two stages would give adequate gain for headphone operation but if the intent was to have something more the extra stage gain was the way to go. I opted for the two stages.

The product detector is next in line and downconverts the signal to audio. I chose the SA602/SA612 IC (either variant is fine) primarily because it works quite well and requires very few external parts to perform its function.

The next element in our receiver is the FET mute switch, which is intended to mute the audio during transmit. It does mute the audio but not completely which enables the signal monitoring that I mentioned earlier.

Finally is the audio amplifier stage, which has been configured for a gain of 200 (23 dB). There is plenty of volume and in some cases enough to drive a loud speaker. I chose the venerable LM386 IC for implementation. There are later IC's that may have some advantages, but this is a tried and true circuit with sufficient performance and can be constructed without problems.

So in order to summarize, we find that our receiver will contain the following stages:

- Bandpass Filter, 200 kHz wide at 7.1 MHz (On the receiver front end and a common low pass filter for both Rx and Tx) 3 dB loss.
- Optional receiving RF amplifier. 20 dB gain
- Mixer stage (Homebrew Double Balanced Mixer (DBM) or SBL-1) 6 dB loss.
- Local Oscillator (12.228 MHz Super VXO + Amp stage 2N3904 with a Band Pass Filter & 2N3904 Amplifier to drive the DBM at 7dBM)
- Post Mixer Amplifier (A strong transistor [2N2219A] with 15 dB gain + 6dB pad to reduce impedance variations with signal level)
- Crystal Filter (Four pole at 5.185 MHz, input /output 50 ohm match to ~ 150-180 ohms. Band width to be less than 1KHz using 330PF coupling capacitors.) 4 to 6 dB loss.
- IF amplifier (2 Stage Hybrid Cascode ala W7ZOI/WA7MLH design 2N3904's & J310's) 40 dB gain.
- Product Detector/ Carrier Oscillator (NE602, SA602/612---- 5.185 MHz. Simple implementation and low part count) 14 dB gain.
- Audio Amp (LM386) 23 dB gain
- Mute Circuit (2N3819)

In all, these stages produce about 90 dB of throughput gain commensurate with our design goal of 83 to 93 dB.

A discussion on gain throughout the transmitter would be very similar to the receiver discussion above. Suffice it to say that the deciding factor in determining the gain required was the limitation imposed on signal level at the transmit mixer output (~ -20 dBm) by the need to avoid spurious signals in that output. A need to limit stage gain for stability set the number of stages required. This led to a requirement for a pre-driver stage (+5.7 dBm output), a driver stage (+20 dBm output) and a final amplifier (+37 dBm output). This was followed by a low pass filter to produce a clean signal due to the harmonics present from the Class C final amplifier output.