Parameters associated with Transceivers, Amplifiers, And Transverters

A Talk given by

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The Talk will give an overview of some important parameters associated with transceivers, amplifiers and transverters and how to test them.

Since the function of HF & VHF units are similar, parameters and testing will fit both.

The talk will start on

(1) Transceivers, starting with the receive part, then the transmitter.

(2)Amplifiers

(3)Transverters

(4) Practical demonstration of measurements for transceivers, amplifiers and transverters

RECEIVERS (RX)

The most important criteria with a RX is …

Can you hear a signal?

If you can hear something then the RX has some sensitivity.

When looking at specifications, this is termed as RX sensitivity and would normally be expressed as a RF signal level, for a given audio signal/noise ratio.
(The audio signal to noise ratio typically being 10dB.)
The RF signal level can be quoted in microvolts (uV) which i s 1 millionth of a volt, or the equivalent signal level in dBm.
In this case it is relative to 1 mW into a 50 Ω load (or 223.6 mV)

$$20 \log (\text{signal} / 223.6 \times 10^{-3})$$

With FM RXs, 12 dB SINAD is often quoted.
(SINAD stands for signal, noise and distortion)
In some cases such as in ARRL reviews, the MDS is quoted. MDS stands for

Minimum discernable Signal

where the Signal to Noise (S/N) is 0 dB.
This is where the Signal = Noise
In most cases the measurement taken is

(S + N)/N or

$$\frac{\text{Signal + Noise}}{\text{Noise}}$$

At low signal levels the difference between S/N and (S + N)/N can be high and as the ratio improves, the difference is minimizes.

At 0 dB S/N, S+N/N = 3 dB

Ideally for a correct measurement the level meter should respond to the RMS value of both noise an d tone.
(such as with a thermal type meter HP 3400 or a true RMS voltmeter Fluke DVM with true RMS capabilities.)

Measurements can be made on an average responding meter such as an AF (Audio Frequency) millivoltmeter or power meter.
A well shielded RF signal generator is needed for this measurement. If a commercial generator is available, then use that. However a well shielded crystal oscillator with attenuators can be used. (double shielded enclosure)

With a typical HF RX operating in a 2.4 kHz SSB bandwidth
The input signal required for measurement for 10 dB S+N/N is typically 0.3 uV or –117 dBm. (20 log ($0.3 \times 10^{-6} / 223.6 \times 10^{-3}$)
There is greater atmospheric noise at HF frequencies so having a more sensitive receiver is not required.

With a VHF RX in a 2.4 kHz SSB bandwidth, the signal level for 10 dB S+N/N is typically 0.125 uV or… -125 dBm, so hence the requirement for a well shielded signal generator. If you are measuring the MDS then the signal generator level would be ~ 10 dB lower.
When checking a FM receiver (25 kHz channel spacing) then the signal generator is set for 3 kHz (60 % of peak deviation.. 5 kHz) and a measurement is made for 12 dB SINAD with a SINAD meter. Typical figures are 0.2 uV (-121 dBm) for 12 dB SINAD

With the signal generator further tests could be done to look at the performance of the RX.

For example with a SSB RX one could look at the Automatic Gain Control (AGC) specifically the AGC threshold. For HF receivers this is typically about 1 uV (-107 dBm) and for VHF 0.3 to 0.5 uV (-117 to –113 dBm). The threshold is set purposely high so that the input signal attains a significant S/N in the receiver before the gain is decreased.

If the incoming noise level is high (operating AGC), the signal S/N may be degraded.

Also <u>AGC range</u> could be checked. Some RX's have limited AGC range as AGC is operating on one device. (Elecraft K2)

If one is able to switch the RF signal on and off, with a circuit similar to a noise blanker then the AGC attack and decay times can be o bserved as well as any audio overshoot (the POP heard on earlier Tentec transceivers)

As one tunes the RX away from the signal then the response of the filter can be seen. This is dependent on the quality of the filter (number of poles) and circuit design. Bad circuit design can cause the signal to bypass the filter. (FT221 users note. I can hear signals out to about 10 kHz). Linear wound inductors can actually radiate strong IF levels and toroidal inductors are preferred.

RX's often have a roofing filter between the 1st mixer and the 2nd narrower filter. The filter is used when upconverting to a high IF or in the case of a noise blanker.

Ideally there should be minimum gain (if any) between the two filters. As is often the case there can be considerable gain between these 2 points (Kenwood TS700 and some Icom HF RX just to name a few) As the input signal is outside the narrow SSB filter there is no AGC action and strong signals can degrade RX performance markedly until the RX is tuned past the response of the roofing filter. On a SSB RX the roofing filter can be 10 - 40 kHz wide. Similar degradation can also occur with an FM RX when the main selectivity is done at 455 kHz. This can affect the adjacent channel performance

If a signal level is increased markedly… 100 dB or more above the noise level, the gain of the stages in the front end of the RX can actually compress. With RX this is called <u>blocking</u>.

Further tests with low noise signal generators (or crystal oscillators) can reveal the effect of <u>reciprocal noise</u> in receivers. Phase Noise on the oscillators in the RX gets translated down to IF frequencies. If a strong

signal is off channel (eg 10 kHz) then this noise can degrade or obliterate a weak signal. (Note users with synthesized or PLL oscillators in RX …Non synthesized oscillators win the day… For example in VHF the Icom IC202 or TS700. In HF RX, VFO's mixed with crystal oscillators are very low noise close in (earlier Tentec, earlier Yaesu).
However, in most cases as one tunes further away from the carrier the PLL or synthesized oscillators are superior.

If 2 strong signals of equal level are introduced into the RX, outside the RX SSB or FM passband, there will be a level where the non linearities in the front end of the RX produce a mixing (or intermodulation) product that will appear at the noise level. The difference between the noise level and the level of the two signals is called <u>spurious free dynamic range (SFDR)</u>

Under normal QSO conditions the effect of these is not normally noticeable, however as signals change due to enhanced propogation, adjacent channel activity or contest operation, then the effect of any of the items noted on previous pages can degrade your reception of the wanted station.

TRANSMITTERS (TX)

In order to contact someone the TX requires 2 things.
Firstly that the TX is transmitting power on the correct frequency and that information is passed in a way that can be understood.

TX operation on the correct frequency can be verified by measuring the TX output on a frequency counter or scanner. With most modern Txers the drift of the crystal oscillators is minimal and it is rare that the transmitter is more than a few kHz off frequency after many years of intermittent use. VFO controlled HF transmitters offer similar orders of drift over time.

Occasionally a crystal may jump to another frequency as happened in my FT221. The crystal jumped ~ 15 kHz and required replacement.

It is recommended that the crystals be ordered preaged. The crystal s are stressed at ~ 125 ^{0}C for a time in order to reduce the drift that the crystal experiences over time. At higher frequencies the effect of having this done is significant. A crystal that is not preaged may exhibit a +ve or –ve drift for a number of years gradually reducing.

The power of a TX may be verified with a terminating power meter or an Inline Power meter such as those commonly available from many suppliers (Diawa, Bird,etc)

If using low powers then a 50 Ω termination with a diode detector should provide a satisfactory indication of power. The power can be calculated relatively easily from the voltage. This technique can be used quite easily up to a number of GHz. At higher powers a coupler is used to red uce the amount of power reaching the detector. At HF frequencies this is done through transformer action and at VHF and above frequencies a stripline adjacent to the main line couples power to the low level detector.

The adjacent striplines are frequency sensitive and can couple too much power off the main line at higher frequencies. This may lead to over disappation of the low power resistors or inaccurate Power/SWR readings

The verification of CW/FM power is relatively easy as the power reading is constant, however when SSB can provide misleading results when using a meter. Peak holding circuits in meters are recommended, as they give a more accurate indication of Peak envelope power (PEP) when used with speech.

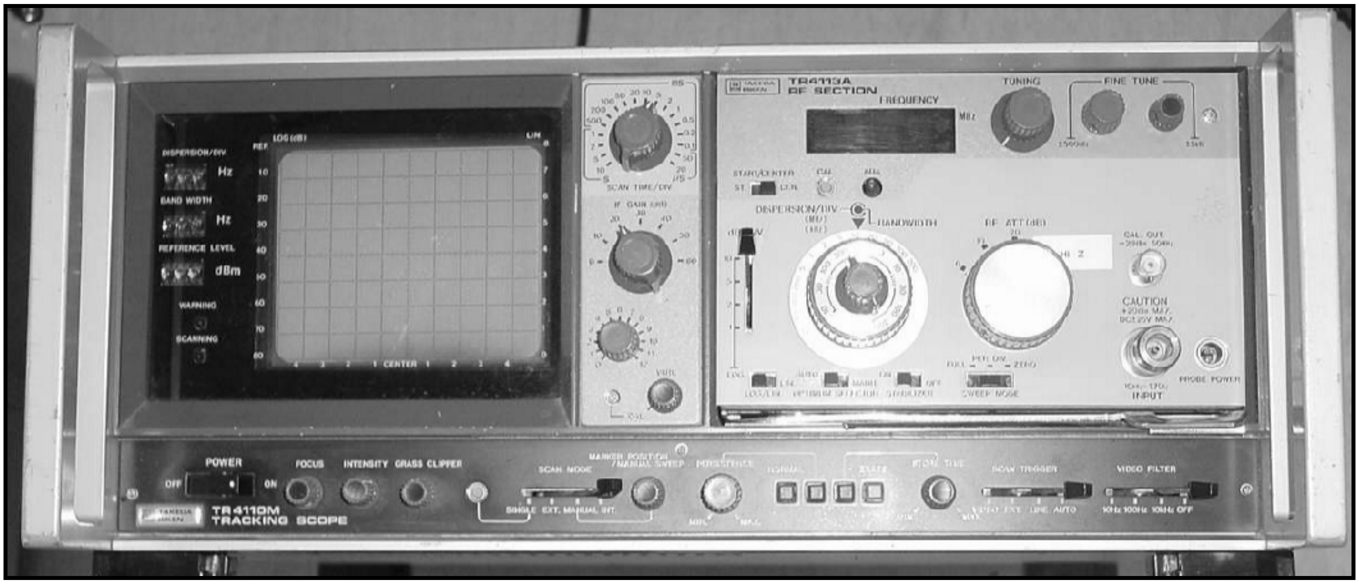
The TX has been measured at operating at the correct frequency and power but how do you know that all that power is at the correct frequency?

In earlier days a wavemeter was used to indicate that circuits were tuned to the correct band. (In its simplest form it was tuned circuit going to a bulb) At the last Hamilton Market day we sold one.

In the last 30 to 40 years a new piece of apparatus has become available to indicate the presence of signals. This is called the Spectrum Analyser and is essentially a tunable RX with a display. They in dicate relative amplitude (normally in dB) on a vertical scale and frequency to the horizontal scale.

Some analysers can cover many GHz (40 GHz) from a scan covering only a few hundred Hz around a particular frequency or covering the whole 40 GHz. New analysers of that range are significantly expensive (many 10's of $1000's).

However earlier spectrum analysers (SA) are now available starting at around $1000. Second Hand Spectrum analyzers can be purchased locally or from suppliers in Australia. Simple Spectrum analyser kits can be purchased from USA.
I have this 1.7 GHz Spectrum Analyser from a NZ source if anyone is interested. Enquiries at the end of the session (after demonstration)



Spectrum analysers are a most useful tool and provides a confirmation check that everything is operating correctly.

Spectrum analysers need not be used with TX'ers. They may be integral to some RX designs to indicate activity on the band. This may take the form of a panoramic display or sometimes signals are decoded with a computer and displayed such as with some digital modes (eg PSK31) or computer based transceivers (DSP-10)

Getting back to using Spectrum analysers with TX'ers. The analyzer can be tuned to investigate the presence of harmonic signals. For example some HF TX'ers may interfere with low TV channels due to the presence of harmonics in the TX output. The analyzer may display these.

Some TX'ers (homemade and sometimes commercial) may have significant spurious signals, if the unit is not aligned correctly, overdriven, unstable or maybe the unit has drifted out of alignment. Some spurious signals maybe inherent in the units design.

As you can see, an analyzer is a very useful tool both in the verifying that your existing equipment is operating correctly and with the design and building of new equipment such as Transmitters and Receivers.

Verifying correct operation of your transmitter
FM

In communicate satisfactorily the correct deviation should be set in your transmitter. If you transmit at 75 kHz deviation you may not be heard, let alone understood in a narrowband FM (NBFM) RX. A simple way of verifying deviation on your TX is to get someone to have a listen… this will certainly get you in the ballpark.

With nominal speech, (for 25 kHz channel spacing) peak deviation should be around 3 kHz, with loud speech peaking at 5 kHz. The deviation is limited due to the action of a clipper.

If the deviation is excessive some repeaters cut off speech.

When sending data through Txers, either the deviation is kept deliberately low so that it doesn't come under the action of the clipper, or, the data is fed at a point on the output side of the clipper. Otherwise distortion effects the data.

The modulation of the transmitter may be checked on a Modulation Meter. This meter gives an deviation reading either on an analogue meter or through a graphical display.
Modulation meters cover HF thru UHF channels with deviation up to 100 kHz. They are suitable for use with wide deviation equipment such as broadcast type equipment to narrow deviation (amateur and other services) They can operate on AM also.

In some parts of Europe, amateur and commercial operation is on 12.5 kHz spacing so deviation is significantly reduced.

SSB

A simple way to verify operati on is to get someone to listen. Just make sure that you are not the strongest station on the band and pinning the needle. This will show the deficiencies in the RX rather than the settings of the TX. Don't wind the microphone gain right up, so that other op's can hear kids playing in the street 2 BLOCKs AWAY.

With a good ear one can discern carrier unbalance, signal splatter (due to overdriving the TX or warblies (due to RF getting back into the TX).

On HF frequencies, waveform monitor's were available. The monitor is basically an oscilloscope, coupled lightly to the TX output so that relative amplitudes are looked at. Sometimes they have a signal source (2 tone) which was fed into the microphone socket of the transmitter so that TX linearity could be observed. Due to frequency limitations they were generally available for HF frequencies.

However if one has a low frequency oscilloscope then you can look at HF,VHF and UHF transmitters by adding a converter to observe the signals. This can be a diode mixer, oscillator and amplifier. Keep levels low into the converter (~-10 dBm) so that the distortion is predominantly due to the TX.

The new ARRL book " Experimental methods in RF Design" suggested converting the TX output down into the range of a Compu ter Sound Card. This together with a FFT spectrum analysis programme such as Spectrogram gives greater resolution.

Another solution is a narrow band RX (250 Hz) so that individual signals can be observed… carrier, etc

The solution which gives maximum v ersatility is the Spectrum analyzer.

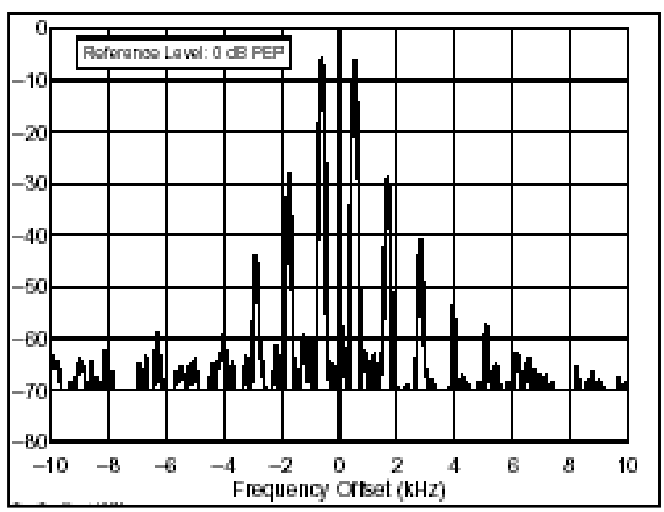
When an audio signal (or 2 audio signals) are fed into a transmitter, 2 things happen. One is, the signal compresses due to high levels, and secondly the 2 tones mix together causing intermodulation products.

One can send an audio tone into the TX and check for output power compression. This can be done simply by setting a single tone audio source (into the microphone socket) so that nominal power is achieved on a power meter. When the tone level is dropped by 10 dB, the output level should drop by 10 dB… in theory. With HF rigs (using valve finals) this should be done intermittently so that the finals don't self destruct.

The gain compression test doesn't tell the whole picture as it doesn't show other non linearities, such as the bias supplies in PA's and earlier stages can become less effective under drive conditions. The Kenwood TS700 and Yaesu FT221 VHF rigs and probably many more transceivers suffer from the base bias supplies on the final transistors de creasing.

In the case of the TS700 this dropped to OV at nominal output. The reason behind it was a series resistor 22 Ω between the bias diode and the base of the Final transistor. A quick remedy was to replace the resistor with a inductor and fit the 22 Ω to ground.

The 2 tone test on a transmitter reveals these problems. The 2 tones can mix both at AF or RF to give rise to intermodulation (IM) products.



The adjacent picture shows an example of TX intermodulation. This being a relatively clean TX.
Depending on the design limitations, the products can go on for a while.

Automatic Level Control (ALC) should be set so that it is starting operation at the nominal power your TX will be set to.
Don't rely on ALC however to control your power as the ALC dynamics may allow overshoot on transients and cause splatter across the band.

Your best power control is the microphone gain control.
USE IT CAREFULLY

What is the best transceiver for HF or VHF. It depends on a lot of things such as mode, the cost, bells and whistles and the type of performance one is looking for…

LINEAR AMPLIFIERS

"Or nonlinear in some cases"

<u>1st Law.</u>
<u>When using amplifiers do not overdrive them…</u>

<u>LINEAR AMPLIFIERS should not be driven past the point where the gain drops by 1 dB</u>. (called the –1 dB gain compression point.)

Often the amplifiers specification indicate a nominal drive level. Do not believe this…

*For example an amplifier with 10 dB gain and capability of ~ 100W. Drive the amplifier with low power (1W) and measure output power (10 W) Gain is 10 dB (10 log P^{out}/P^{in} = 10 log 10). If the drive is increased to 10 watts and the power output is 80 watts then the gain is 9 dB (10 log P^{out}/P^{in} = 10 log 80/10). In this example the amplifier is operating at the –1dB gain compression point.

If the power output at this point is less than 80 watts then the 1 dB gain compression point has been exceeded and the drive from the transmitter must be reduced so that -1 dB gain compression point is not exceeded.

It is quite common for solid state amplifiers to have gain exceeding their quoted figures. Example a 10/100 W amplifier may only require 3 -5 watts for 100 watts output. By doing simple measurements at low drive levels and high drive levels then the -1 dB gain compression point can be found. Amplifiers should not be driven past the -1dB gain compression point as the amplifier quickly saturates and the signal widens significantly.(Your amateur and local neighbours will not like you)The saturated signal will probably create TVI and widen your presence on the band.(Not nice during contests)

The drive level from the transmitter may be dropped by a Power out control in your TX, or an ALC control. Otherwise an attenuator may need to be fitted in series with the AMPLIFIER.

Quite often the Amplifier may also have a RX preamp so this is not quite as severe as it sounds as the RX gain can be reduced quite a few dB without the RX signal degrading significantly. Alternatively an extra length of lossy coax may be used. Making up a 10 dB power attenuator is useful for checking amplifiers if your TX doesn't have a low /high power switch.

Amateur VHF Amplifiers specify a nominal output power and drive level. For example a Tokyo HY Power HL 37V 2 M SSB/FM/CW amplifier specifies 3 watts in for 32 watts out. Bench tests revealed that 0.5 watts in gave 29 watts out, while 2 watts gave 38 watts out

Gain in dB at 0.5 watt drive = 10 log (29/0.5) = 17.6 dB

Gain in dB at 2.0 watt drive = 10 log (38/2.0) = 12.8 dB.

At 2 watts drive the amplifier's gain has dropped by 4.8 dB, as 2 watts has exceeded the –1 dB gain compression point significantly. In use the drive level should be 0.5 to 0.75 watts to maintain a clean signal on the band.

To look at it another way

For an input increase of.5 to 2 watts or 6 dB [10 log (2/.5)] the output has increased from 29 to 38 watts or only 1.1 dB…10 log (38/29)!!!

*In the previous example the input goes up by 10 dB while the output goes up by 9 dB (-1 dB gain compression).

When the –1 dB gain compression point is exceeded, the transmitted signal is distorted in the amplifier and the increase in power is mainly due to the increased level of these distortion products. (Intermodulation levels in the amplifier increase with excess drive). The difference in output power level between linear (-1 dB compression point) and saturated power can be quite small.

!!! PLEASE CHECK YOUR AMPLIFIERS !!!!
AVOID SPLATTERING YOUR SIGNAL ACROSS THE BANDS

Perhaps your local club can have a night where VHF/ UHF Linear amplifiers can be checked for correct drive level using this technique.

During the time I lived in England, I was operating on 2 M SSB when an amateur came on operating SSB through a class C Amplifier. I found him more than 50 kHz away and a queue had already formed by the time I found the frequency. (Arrrgh!!)

The DC bias circuit in Transistor Linear Amplifiers must be stable at nominal output levels otherwise your signal widens.

At low drive levels or in manual TX m ode on the Amplifier, measure the DC going to base of the RF transistor (On the cold side of the choke going to the base) (Bipolar transistor assumed) It Should be ~ 0.7 volts. The meter may need to be an analogue one due to RF interfering with DVM's. At high drive levels the variation should be less than 50 mV.

A quick note on RX Low noise amplifiers fitted in power amplifiers: -
Just use enough gain to improve the incoming signal. Having excess gain in a RX system can be detrimental to performance under strong signal conditions. Note the strong signals may occur inband or out of band (TV ,Cellular, FM Broadcast, FM Mobile, STL's, Radar, and so on.

TRANSVERTERS

1ST RULE

All Transverters should be checked on a Spectrum Analyser before use. Transverters can have a number of spurious and stability issues.

Some units are on the verge on instability just sitting on the bench. Instability can occur both in the RX side and the TX side. Even putting the unit in a box can affect the stability dramatically.

Some units have less than ideal (read disappointing,unclean,dirty…) rejection of unwanted signals such as IF drive, Local Oscillator, TX image and TX intermodulation products

This may be due to inferior design, design errors, (DEM 1296 MHz users take note) circuit radiation, temperature drift, component aging, alignment, voltage sensitivity, inherent instability and so on.

It is highly recommended that both commercial and homemade transverters be put on a Spectrum analyser to verify their cleanliness under nominal drive.

Some units can be overdriven when nominal power is sought. 1296 MHz transverters of UK origin can exhibit gain compression of the order of 8 dB. The same manufacturer's 432 to 28 MHz transverter exhibits bias collapse when used at its nominal 10 watts output. In fact the DC voltage on the base of the final transistor is actually negative!!! The base bias can be seen to start dropping at ~ 400 mW output…

Similar gain/compression checks as outlined for amplifiers should be done for transverters

NOISE FIGURE (NF) of Transverters and LNA's (Low noise amplifiers)

Are you able to hear signals as well as you should?

All components generate noise or have some loss. At HF frequencies a higher noise/loss in RX circuit design is acceptable as t he incoming level of atmospheric noise is generally high.

At VHF and above, atmospheric noise is lower so more sensitivity is required in order to hear weak signals.

The sensitivity of a RX can be determined by doing a S/N or MDS check.
In the case of transverters or LNA's, a Noise Figure (NF) check is normally done.

A simple test can be to point the antenna, LNA, (or ~~LNA~~), transverter (RX converter) feeding into a SSB RX, towards ground, then to a cold part of the the sky (Don't point towards the SUN… that is extremely HOT. The greater the difference as seen on the S meter/AGC or an AF voltmeter (if AGC is off or below AGC threshold) the more sensitive the setup.

Noise figure essentially is a measurement how much degradation a LNA, RX Converter has, compared to a perfect LNA or RX converter. (one which generates no noise.)

With low noise devices and design, the amount of noise generated is amazingly close to that perfect LNA or RX converter . In some cases within 0.2 to 0.3 dB of perfection.

To do a noise figure check with instruments, a known amount of noise is injected into the LNA or RX converter. The output is then fed to a special receiver, which measures the noise from the LNA or RX converter, both with the noise source on and off. From t his it calculates the amount of noise generated in the unit…

If one was operating at a system at ambient temperature (antenna sees the same temperature as the equipment (eg 20 ^{O} Celcius or 293^{O} Kelvin) any improvements in NF would give a similar improv ements in sensitivity. (A drop in NF by 2 dB would increase sensitivity by 2 dB.)

However when an antenna is pointed towards a satellite, it does not see 290 ^{O} Kelvin. It sees maybe 40 ^{O} Kelvin which basically means that an improvement in NF by 2dB, may gain you 4 or 5 dB. So you get something for nothing…

I hope this talk has given an insight into some parameters of Transceivers, Amplifiers and transverters

A DEMONSTRATION follows showing some measurements on transceivers/ amplifiers and transverters.