Harmonic Receivers

1. Introduction

The **Scanlock M2** counter surveillance receiver uses the technique of harmonic mixing to allow rapid scanning of the RF spectrum.
The resultant scans can either be monitored aurally using one of the Scanlock M2 demodulators or visually using one of the Scanlock M2 spectral display outputs.
Harmonic reception is advantageous when used for 'bug' detection as the technique allows numerous frequencies to be simultaneously interrogated for signals thus considerably reducing the time taken to perform counter surveillance 'sweeps'.
Until now Scanlock counter surveillance receivers have employed a method of **Swept Compression** for performing scans.
This method is perfectly adequate for 'fingerprinting' a particular RF spectrum, however analyzing signals captured using this method can become a non-trivial task.
The Scanlock M2 counter surveillance receiver utilizes a second method of scanning, known as **Fixed Compression**, to ease the analysis of RF signals.

2. Conventional Superhetrodyne receivers

In order to understand the harmonic receiver principle the operation of the conventional Superhetrodyne receiver is first discussed.

In a conventional Superhetrodyne receiver a local oscillator (LO) is applied to a mixer in order to convert the incoming RF signal to a second intermediate frequency (IF).

A typical Superhetrodyne receiver topology is shown in figure 1.

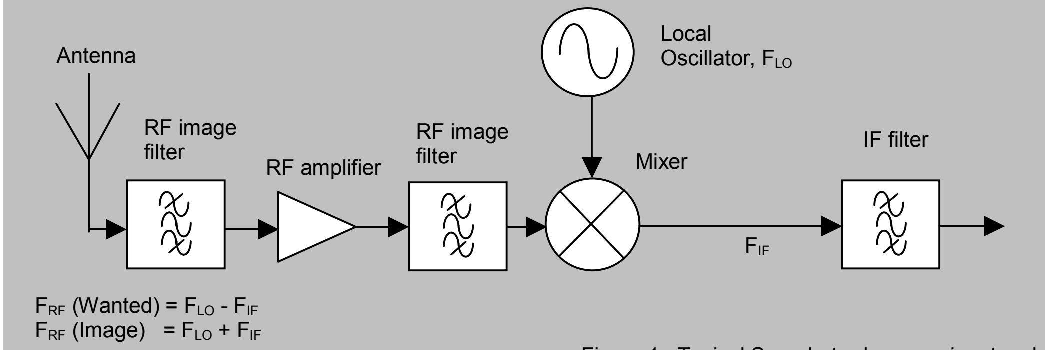

Figure 1 : Typical Superhetrodyne receiver topology

In general a response will be seen at the output of the IF filter when the RF input signal conforms to the following relationship;

$$F_{RF} = n \times F_{LO} \pm F_{IF} \qquad (1)$$

Where F_{RF} is the RF input frequency, F_{LO} is the local oscillator frequency, n is the local oscillator harmonic order ($n = 1, 2 \ldots \infty$) and F_{IF} is the receiver intermediate frequency.

Note: ***For the ideal Superhetrodyne receiver considered here the local oscillator harmonic order equals 1.***

The sensitivity of the conventional Superhetrodyne receiver is given by the following relationship;

$$P_{sens(dBm)} = -174 + 10\log_{10}(IF_{BW}) + F + CNR \qquad (2)$$

Note: The relationship given in (2) only considers internal receiver noise

Where –174 is the thermal noise measured in a 1Hz bandwidth (dBm), IF_{BW} is the final pre-detection bandwidth (Hz), F is the noise figure of the receiver (dB) and CNR is the required carrier to noise ratio for the desired receiver response (dB).

From relationship (1) it can be seen that two RF signals will be converted to the IF, these signals are generally known as the wanted response and unwanted / image response.
In a conventional Superhetrodyne receiver (Figure 1) RF image filters are usually employed to remove the unwanted response prior to the mixing process.
If the RF image filters were omitted the sensitivity given in relationship (2) could actually be 3dB worse due to noise at the image frequency being converted to the IF.

The input frequency plan for the conventional Superhetrodyne receiver (Figure 1) is shown in Figure 2.

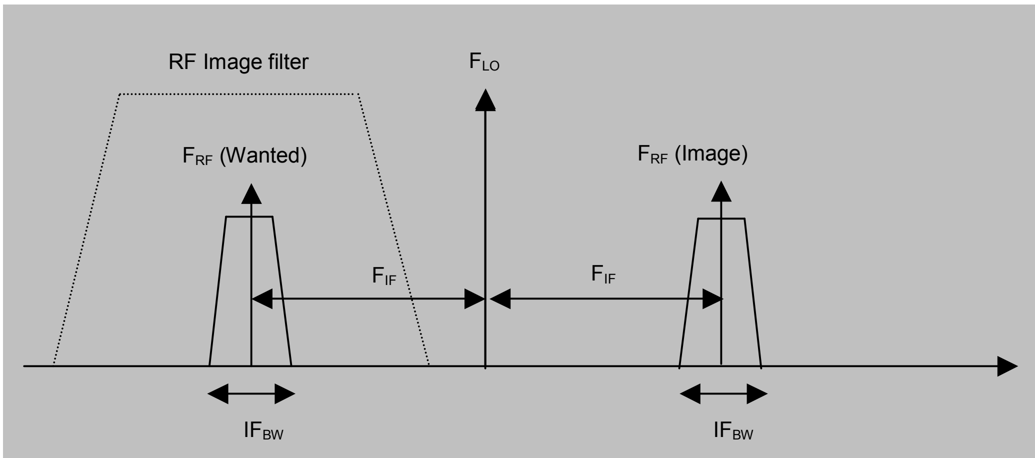

Figure 2 : Superhetrodyne receiver Frequency Plan

In general, a conventional Superhetrodyne receiver will be used where prior knowledge of the RF signal characteristics are known e.g. frequency, bandwidth, modulation etc.

3. Harmonic receivers

Where no prior knowledge of the RF signal characteristics are known the harmonic receiver topology can be implemented to efficiently and rapidly scan for unknown signals.

In a harmonic receiver a local oscillator (LO) is fed via a non-linear junction to the mixer in order to convert the incoming RF signal to a second intermediate frequency IF.

A typical harmonic receiver topology is shown in Figure 3.

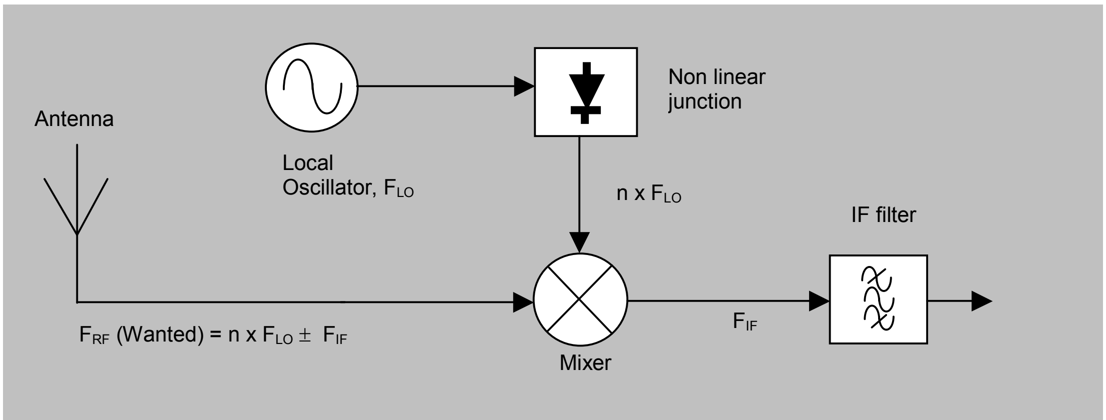

Figure 3 : Typical Harmonic receiver topology

The relationship given in (1) also applies to the harmonic receiver, however unlike the conventional Superhetrodyne receiver the local oscillator harmonic order is not fixed at 1.

The non-linear junction used in the harmonic receiver generates a comb of frequencies spaced at harmonics of the local oscillator frequency, $F_{LO.}$

The harmonic receiver can therefore monitor a number of frequencies simultaneously;

$$N_{mon} \equiv ENB = n_{max} \times IF_{BW} \times 2 \qquad (3)$$

Where N_{mon} is the number of frequencies simultaneously monitored, ENB is the effective noise bandwidth of the harmonic receiver (Hz), n_{max} is the highest order local oscillator harmonic generated by the non-linear junction, IF_{BW} is the final IF bandwidth (Hz) and the multiplication factor of two takes account of the wanted and image responses.

Note: The concept of a wanted and image response is not valid for a counter surveillance harmonic receiver as both signals are potentially wanted.

The sensitivity of the typical harmonic receiver is given by the following relationship;

$$P_{sens(dBm)} = -174 + 10\log_{10}(ENB) + F + CNR \qquad (4)$$

Note: The relationship given in (4) only considers internal receiver noise

Where –174 is the thermal noise measured in a 1Hz bandwidth (dBm), ENB is the effective noise bandwidth of the harmonic receiver (Hz), F is the noise figure of the receiver (dB) and CNR is the required carrier to noise ratio for the desired receiver response (dB).

The input frequency plan for the harmonic receiver (Figure 3) is shown in Figure 4.

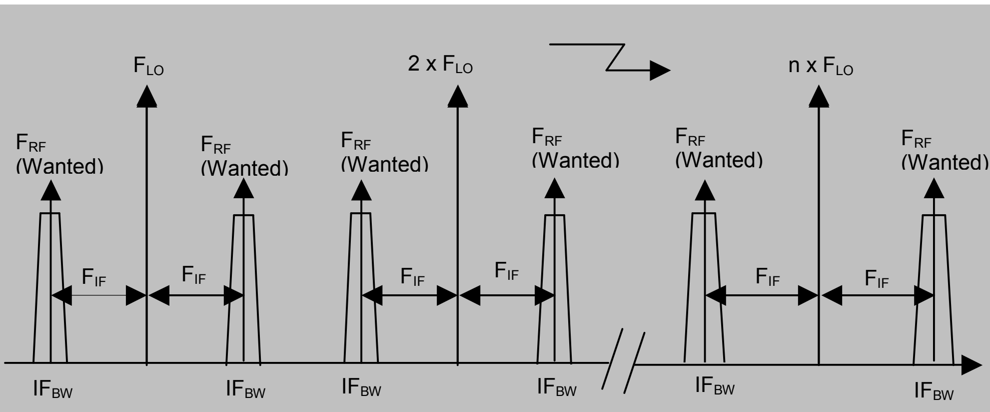

Figure 4 : Harmonic receiver Frequency Plan

4. Swept Compression scanning

Swept Compression scanning involves sweeping the local oscillator frequency, F_{LO}, of the harmonic receiver shown in Figure 3.
When using a Swept Compression scan mode the number of frequencies that can be simultaneously monitored remains as given in relationship (3) and the sensitivity remains as given in relationship (4).

A feature of Swept Compression scanning is that as the local oscillator is swept a single RF input signal can result in numerous responses in the IF.

The number of responses can be approximated using the following relationship;

$$N_{resp} \approx \left[\, \mathbf{trunc}\big((F_{RF} - F_{IF}) \div F_{LO(min)} \big) - \mathbf{round}\big((F_{RF} - F_{IF}) \div F_{LO(max)} \big) \right] + \left[\, \mathbf{trunc}\big((F_{RF} + F_{IF}) \div F_{LO(min)} \big) - \mathbf{round}\big((F_{RF} + F_{IF}) \div F_{LO(max)} \big) \right] + 2 \qquad (5)$$

Note: Assumes RF signal is a single tone, IF bandwidth is infinitely small and sweep resolution is infinitely small

Where N_{resp} is the number of responses, **trunc**(X) rounds X down to the nearest integer, **round**(X) rounds X up to the nearest integer, $F_{LO(min)}$ is the minimum local oscillator sweep frequency and $F_{LO(max)}$ is the maximum local oscillator sweep frequency.

Using Swept Compression scanning it is possible to calculate the actual RF input frequency from a given multiple response ‘fingerprint’.
However this can become a non-trivial task when a number of RF signals are received during a Swept Compression scan.

An effect of Swept Compression scanning is that of displayed bandwidth distortion.
The maximum displayed bandwidth when using Swept Compression scanning can be approximated using the following relationship;

$$BW_{disp(max)} = BW_{RF} \div N_{min} \qquad (6)$$

Note: Assuming the IF bandwidth << RF signal bandwidth

Where $BW_{disp(max)}$ is the maximum displayed bandwidth of the RF signal during a Swept Compression scan, BW_{RF} is the actual RF signal bandwidth and N_{min} is the lowest order local oscillator harmonic capable of converting the RF signal to the IF.

$$N_{min} = \textbf{round}[\ (\ F_{RF} - F_{IF} - 0.5 \times (BW_{RF})\ ) \div F_{LO(max)}\ ] \qquad (7)$$

Essentially as the frequency of the RF signal increases so does the displayed bandwidth error of any of the multiple Swept Compression responses.

Swept Compression scanning is an adequate method for obtaining a signature of the RF spectrum, however as has been discussed RF signal analysis when using this scanning mode can become a non-trivial exercise.

5. Fixed Compression scanning

Fixed Compression scanning involves a combination of harmonic mixing and conventional swept Superhetrodyne receiver techniques.

In a Fixed Compression scan mode a fixed local oscillator is fed, via a non-linear junction, to the mixer in order to convert the entire incoming RF spectrum to a first wide band IF.
The first wide band IF is then swept using a conventional Superhetrodyne receiver to convert the compressed wide band IF to a second narrow band IF.

A typical Fixed Compression mode receiver is shown in Figure 5.

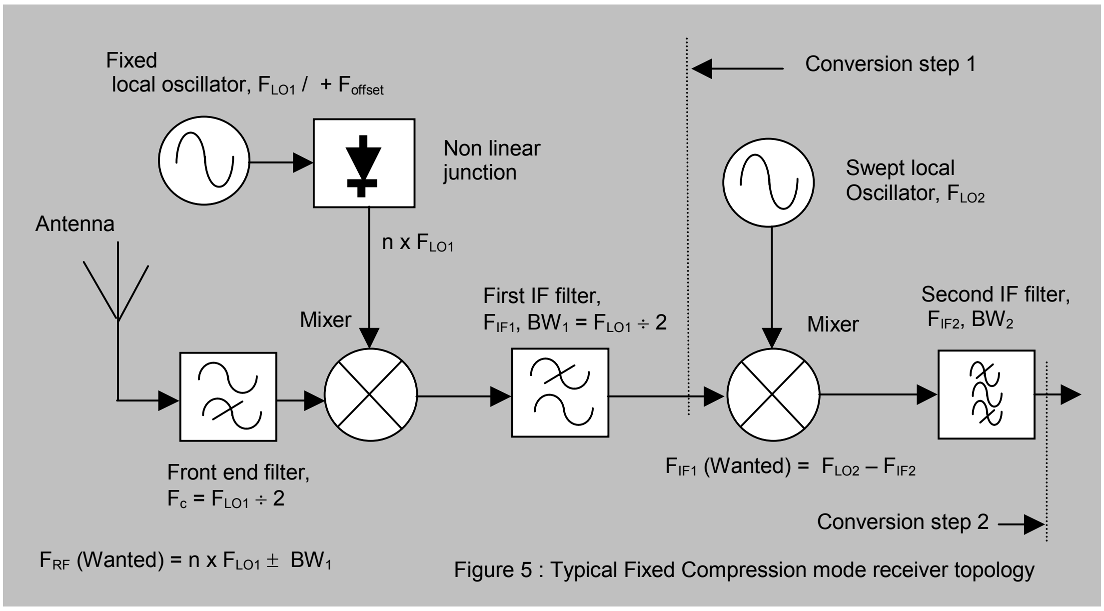

Figure 5 : Typical Fixed Compression mode receiver topology

When using a Fixed Compression scan mode the number of frequencies that can be simultaneously monitored remains as given in relationship (3) and the sensitivity remains as given in relationship (4).

A feature of Fixed Compression scanning is that as the second local oscillator is swept a single RF input signal will result in a single response in the IF.

The actual frequency of the RF signal can be measured by offsetting the fixed local oscillator by a small amount, F_{offset}, and measuring the resultant shift in the first compressed IF signal.

The frequency can be calculated using the following relationship;

If $F_{IF1(a)} – F_{IF1(b)}$ is positive, [low side LO], then

$$F_{RF} = \textbf{mod}\ [\ (F_{IF1(a)} – F_{IF1(b)}) \div F_{offset}\ ] \times F_{LO1} + F_{IF1(a)} \qquad (8)$$

If $F_{IF1(a)} – F_{IF1(b)}$ is negative, [high side LO], then

$$F_{RF} = \textbf{mod}\ [\ (F_{IF1(a)} – F_{IF1(b)}) \div F_{offset}\ ] \times F_{LO1} – F_{IF1(a)} \qquad (9)$$

Where **mod** [X] returns the magnitude of X, $F_{IF1(a)}$ is the first IF at F_{LO1} and $F_{IF1(b)}$ is the first IF at (F_{LO1} + F_{offset})

Fixed Compression scanning can also be used to analyze the RF signal bandwidth.
The displayed signal bandwidth when using Fixed Compression scanning can be approximated using the following relationship;

$$BW_{disp} \approx BW_{RF(signal)} \qquad (10)$$

Note:* *Assuming the IF bandwidth, BW_2 << RF signal bandwidth

Where BW_{disp} is the signal bandwidth indicated on the spectral display output and $BW_{RF(signal)}$ is the actual RF signal bandwidth.

A further feature of Fixed Compression scanning is that the scan resolution chosen for the sweeping the first IF translates directly to scan resolution in the RF spectrum.

$$Scan_{IF1(res)} = Scan_{RF(res)} \qquad (11)$$

Where $Scan_{IF1(res)}$ is the sweep resolution of the first IF bandwidth, BW_1, and $Scan_{RF(res)}$ is the sweep resolution of the entire RF spectrum.

As the first IF bandwidth, BW_1, is considerably smaller than the RF spectrum, the entire RF spectrum can be rapidly scanned.
The potential increase in scan rate over a conventional Superhetrodyne receiver can be approximated using the following relationship;

$$Scan_{RI} \approx (\ 2 \times BW_{RF}\ ) \div F_{LO1} \qquad (12)$$

Where $Scan_{RI}$ is the scan rate increase relative to a conventional Superhetrodyne receiver scanning at the same resolution, BW_{RF} is the entire RF spectrum bandwidth captured by the receiver and the multiplication factor of two takes account of wanted and image responses.

The input frequency plan for the Fixed Compression mode receiver with a single RF input signal is shown in figure 6.

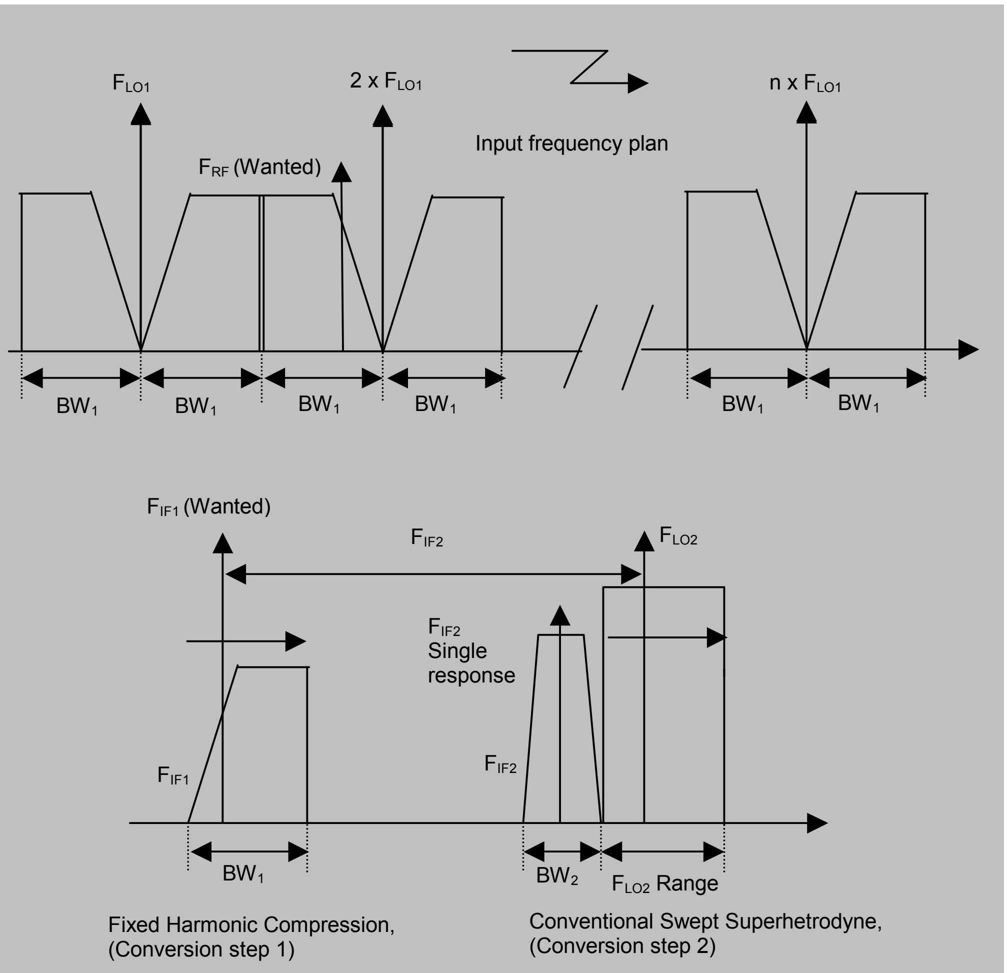

Figure 6 : Fixed Compression mode frequency plan

6. Summary

When there is a requirement to scan a large area of spectrum for unknown signals the harmonic receiver technique can considerably reduce counter surveillance search times compared to the conventional Superhetrodyne receiver.
As with most things, there is a trade-off for the increase in scan speed.
The harmonic receiver monitors a number of frequencies simultaneously which increases the receiver effective noise bandwidth.
The harmonic receiver will therefore be less sensitive than the equivalent conventional Superhetrodyne receiver.
However the loss in sensitivity should not cause a problem when performing a counter surveillance scan as the RF signals of interest will be local to the ‘sweep’ area and should therefore be received at a relatively high level.
The two modes of harmonic scan have their relative merits.
The Swept Compression scan can be used as a ‘fingerprint’ or signature of the RF spectrum of interest.
The Fixed Compression scan can be used for the purposes of signal analysis, RF frequency and modulation bandwidth can be easily measured using this mode.