APPLICATION NOTE

The Care and Feeding of Shortwave (HF) Multicouplers

August 2010

1. Introduction

A multicoupler is designed to allow a number of radio receivers to be connected simultaneously to the same antenna. A properly specified multicoupler can improve the performance of a radio receiving system, whether for communications or surveillance, and provide system protection from off-air electrostatic discharge and high level CW signals. However care must be taken in specifying and designing a multicoupler for a specific purpose and frequency band.
From our point of view, the essential difference between the radio frequency range 10kHz to 30MHz (HF) and higher (VHF/UHF) frequency ranges is the way in which the ambient noise level varies.

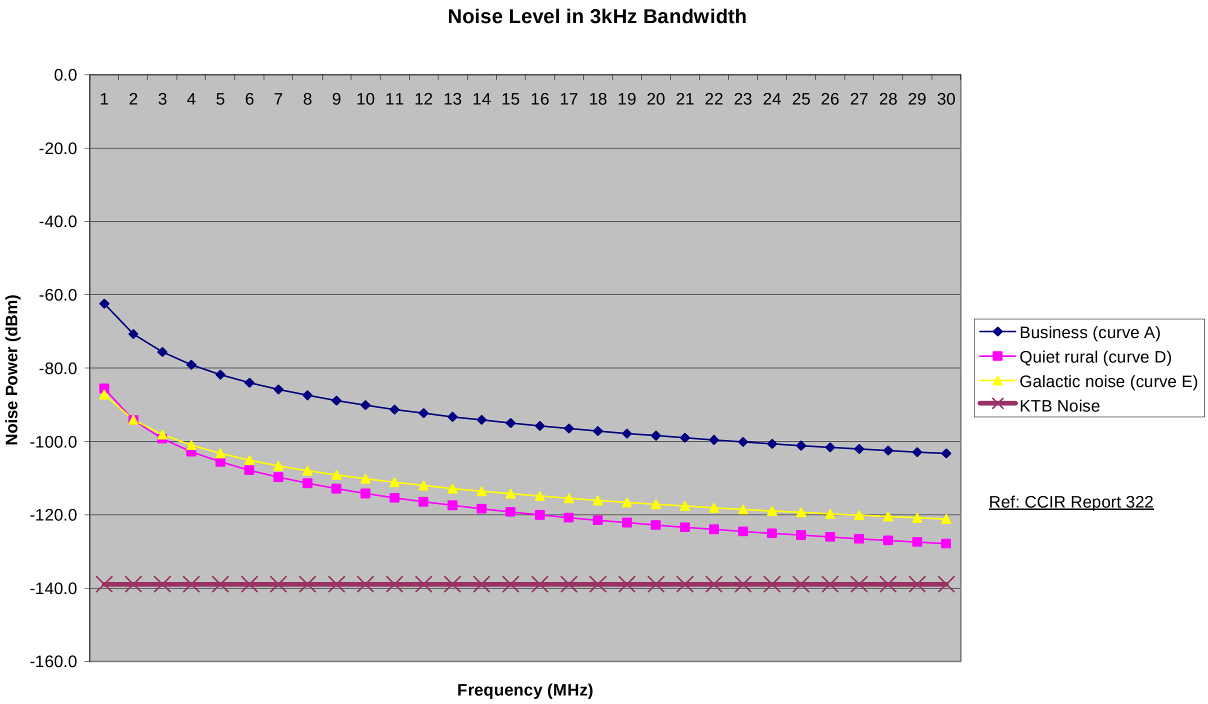
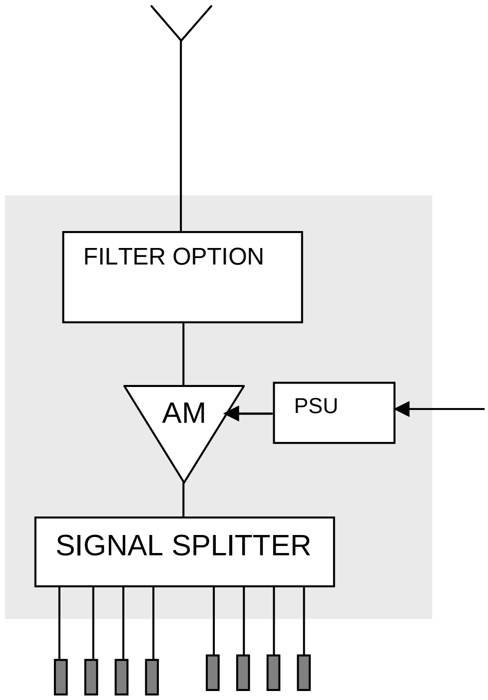


Figure 1 shows the anticipated noise level to be expected from a shortwave monopole antenna in a 3kHz bandwidth from man made sources and Galactic noise. It will be noted that even the natural noise level is well above thermal noise and varies as:

1-3MHz > 40dB above KTB noise
3-30MHz > 20dB above KTB noise

Above 30MHz, the natural noise tends to reduce towards the KTB level and (natural) external noise is not usually a consideration at VHF/UHF.
This fundamental fact dictates much of the specification that HF multicouplers must achieve for system performance to be satisfactory and the contrast between them and their VHF/UHF counterparts.

2. Basic Theory of Operation



The functional block diagram of a typical one input and 8 output multicoupler is shown in figure 2. A received signal is carried to the input band pass filter and to the preamplifier.
The output from the amplifier is divided 8 ways and the outputs taken to the receiver inputs.
The multicoupler can be purchased as a single module for wall or bulkhead mounting in a 19" rack or as a separate 19" rack mounting unit, separate from the radio receivers and antennas and complete with its own mains power supply.
Multicouplers for HF operation are complex circuits and generally come in 19" rack mounting units.

3. RF Performance of Shortwave Multicouplers

1.1 Noise Figure

The output noise floor of the multicoupler can be calculated as -128dBm for a 10dB noise figure.
In the HF band, this level is 10dB below the lowest output level of the galactic noise received at the front end of the multicoupler that is amplified and transmitted at the outputs.
A 10dB noise figure is generally therefore adequate to ensure that the noise performance of the multicoupler does not compromise the performance of the system – in most cases.
There are some customer's receiver sites where external noise is claimed to be much lower than the CCIR figure. In these cases a lower noise figure specification may be justified.
In practice noise figures of 7dB are relatively inexpensive to achieve and so the multicoupler front end of the system will usually improve the system noise figure, relative to a single receiver operating separately.

1.2 Intermodulation

The worst enemy of good system performance in wideband shortwave systems is intermodulation. Intermodulation occurs when two or more signals mix in non-linear networks to form spurious products. These spurious signals, generated within the radio feeder system itself, can so easily look to an operator like real off-air signals and so completely confuse the operation of a communications system or the collation of short wave spectrum surveillance data.

2.1.1 Cause of Intermodulation

The spurious intermodulation signals are generally represented as the results of higher order terms in the network transfer function (filter, amplifier) and comprise a Fourier series, such as:

$F(out) = ASin\omega t + BSin^2\omega t + CSin^3\omega t + \ldots\ldots\ldots etc$

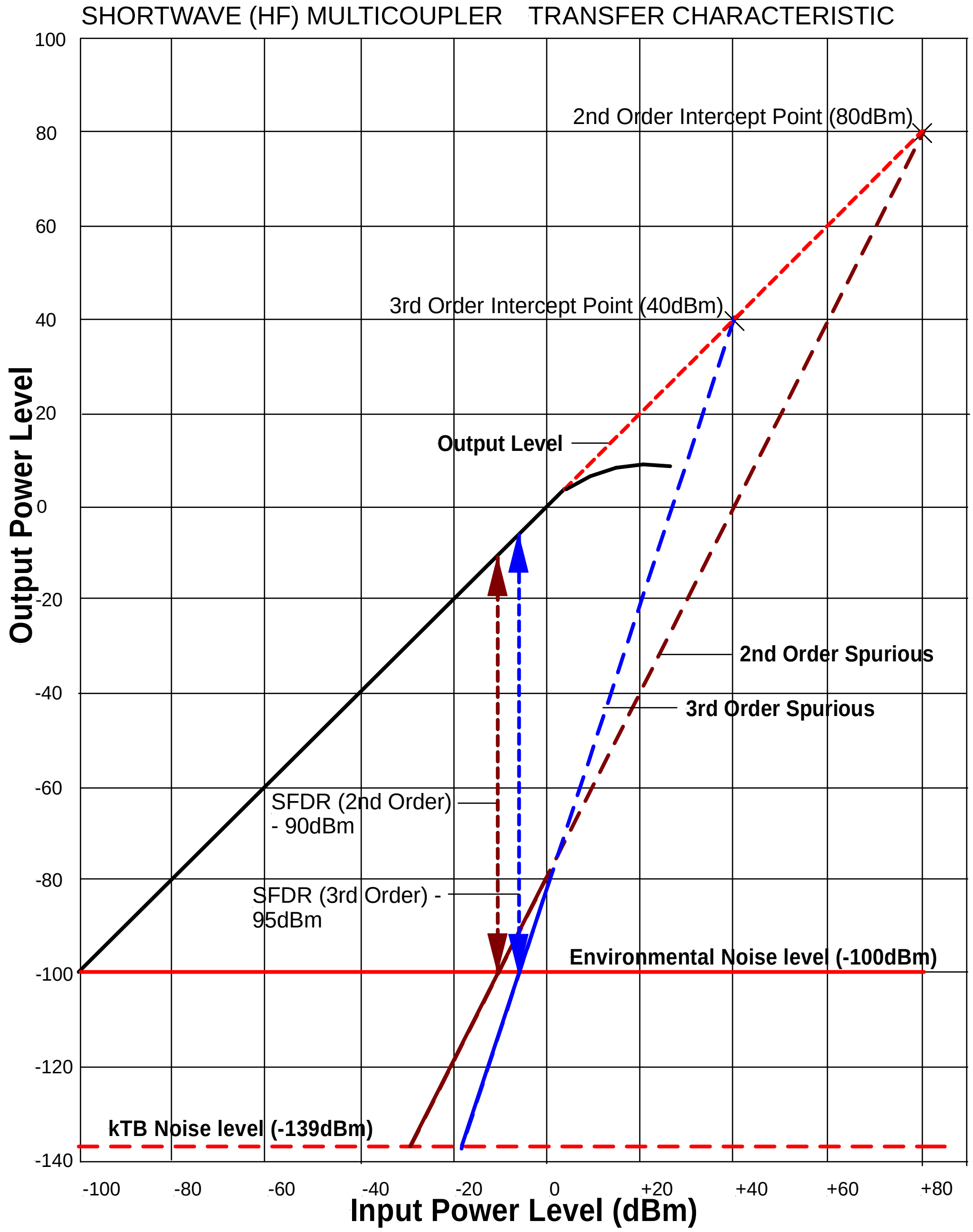
$F(out) = ASin2\pi\,(F1+F2)t + BSin^2 2\pi\,(F1+F2)t + CSin^3 2\pi\,(F1+F2)t + \ldots\ldots\ldots etc.$

It is usually assumed that the most important spurious are 1st and 2nd order products, such as

(F1+/-F2) and (2F1+/-F2) etc. The square and cube terms of a number less than 1 are considered vanishingly small.

The 2-3OMHz band covers four octaves of frequency so there is plenty of room for both the 3rd order (2F1 +/-F2) and the 2nd order (F1+F2) intermodulation products to appear to look like real signals, when the system open to the full band. The front-end multicoupler and/or pre-amplifier are indeed wideband in most cases. The first band limiting element in the radio system is usually the front-end pre-selector in the receiver, which is after the multicoupler.
So, intermodulation in the multicoupler will always affect the system adversely.

To quantify the intermodulation effect, we need to look at the levels of spurious actually generated.



The diagram illustrated the relationship between the 2nd and 3rd Order Output Intercept Points (OPIP) and the intermodulation spurious produced relative to the fundamental output of the

device. The non-linear characteristic produces 2nd order (F1+/-F2) and 3rd order (2F1+/-F2) spurious signals in accordance with the rules illustrated above.
Thus, the ideal multicoupler has zero gain and the highest possible OPIPs points which will in turn yield the highest 2nd and 3rd Order spurious free dynamic range.

2.1.2 Spurious Free Dynamic Range

The spurious free dynamic range (SFDR) is important because it sets the highest signal which can pass through the device without developing a spurious signal of greater amplitude than the noise floor of the system. So, a system designed to identify and monitor low level signals off-air, in the presence of higher in-band signals (broadcasts and friendly communication signals) can operate without generating intermodulation spurious with interfering signals up to a level set by

Highest Signal (dBm) = Noise floor (dBm) + SFDR (dB).

Note that the level of the noise floor in the HF band is set by the ambient (environmental) noise and not by the system itself. The noise figure of the system is usually quoted for a 3kHz bandwidth, which sets the thermal (kTB) noise at -139dBm. The noise generated by the system is given by

Noise generated = kTB*(F-1)*G

Where k= Boltzmanns Constant
T = absolute temperature
B = bandwidth (3kHz)
F= noise figure (as a factor)
G = gain of the system (as a factor)

If the feeder system (including the multicoupler) produces noise less than the ambient noise, then the feeder system will have no influence on the minimum discernible signal, which will usually be some 3dB above the ambient noise. A typical multicoupler noise figure is 7dB, which leaves the output noise floor at -132dBm, a full 30dB plus below the usual level of environmental noise.

2.1.3 Techniques to Minimise Intermodulation

The solution to this intermodulation problem is either:

- Prevent the formation of the spurious signal at source through linear amplification or
- Cancel the spurious using signal of equal frequency and power in anti-phase.

Older systems used amplifiers with high power output capability in the hope that such amplifiers would be very linear when used at low levels of power. This is the same approach as HiFi buffs and it works – to an extent. The penalty paid was the high power consumed in class 'A' amplifiers, higher operating temperatures, which leads to lower component reliability and component aging. In large systems, fuel costs are also a consideration.

The modern way is to use negative feedback and positive feed-forward to achieve high linearity with relatively low power amplifiers. This has the advantage of lower prime power, which is easier on the fuel bill and reduces waste heat, which makes for higher reliability of components.

The most spectacular results are obtained with the feed forward technique, which was re-introduced into this application by Raven Research some time ago. In this application, we use such techniques for a minimum divide ratio of 32:1 (32-way coupler). The amplifier has a gain of 18dB and $2^{nd}/3^{rd}$ IP of 120/60 dBm respectively for a power consumption of 20W. The feed forward technique also improves the noise figure which is typically 5dB for this amplifier.

1.3 Isolation

In shortwave multicouplers, Raven Research uses 'lossless' power dividers. These are ferrite core transformers designed to divide the power with minimum signal loss, typically a few tenths of a dB more than the divider loss (3dB). These designs have inherently higher port-to-port isolation than resistive dividers when properly terminated.

The Output-to-Output isolation is important in preventing local oscillator spurious emanating from the receiver feeder passing to the input port of the adjacent receiver and appearing as a new signal.

Reverse isolation (Output-to-Input) is important lest any LO or other spurious signal emanating from one of the receivers passes to the antenna feeder and transmits to an astute and capable adversary.

1.4 Gain

The gain of the unit needs only be set to reduce the effect of the cascade and preserve the receiver noise figure for the system (that is, not make it worse).
Modern surveillance receivers boast a noise figure of 11dB with pre-amplifier but only 20dB without the amplifier. As we shall see below, unless the pre-amplifier has a high spurious free dynamic range or a narrowband pre-selector, the system might be better off without it.
Nevertheless, using the classic formula,

$F_{tot} = F_1 + F_2-1/G_1$

Where F_1 = Noise figure of first stage = 7dB = (factor) 5
F_2 = Noise figure of second stage = 11dB = (factor) 12.59
G_1 = Gain of first stage = 2dB = (factor) 1.6
F_{tot} = Noise figure of overall system

Overall Noise Figure = 5 + (12.59-1)/1.6 = 10.9dB

1.5 Front end Protection

Shortwave front-ends are quite vulnerable to electro-static discharge because most of the energy in a lightning strike exists in the HF band and below. They are also prone to damage by high power transmissions, particularly from high power mobile transmitters parked near the system antenna, which will typically have a high effective aperture.
Raven shortwave multicouplers are usually protected with a gas discharge tube (90V flash over) and a diode chain. This circuit will protect the front-end circuit from +40dBm CW and 50kV pulse with 1uS rise time and 50uS duration.

The RR1110 series has an additional protection circuit which will actually shut down the pre-amplifier and reduce the gain, once the input power exceeds +15dBm. This additional feature is intended to protect the following receiver front-end, wherever the system is exposed to high power in-band transmissions.

1.6 BITE

The RR1110 series is very much intended as a system product, to be integrated into a receiving system. With this in mind, built-in-test-equipment (BITE) circuits are included in the design. These circuits monitor the performance of the bias on the two elements of the push-pull amplifiers which are at the heart of the design. If these currents go out of balance by more than the permitted amount, the operation of the multicoupler is not immediately compromised. The unit will usually fail gracefully over a period of time.

However, the BITE circuit is immediately triggered and the external alarm is activated.
This gives the operator immediate warning of an impending failure and information on the location of the endangered unit.

1.7 Mechanical

The RR1110 series of multicouplers is housed in 19" rack mounting units, 1U high (4,8,16-way) and 2U high (32-way)

Other mechanical arrangements can be provided to order save space or provide for alternative mounting and/or housing arrangements. The RR1115 series, for example, provides up to 16 multicoupler modules in a single 19" rack mounting unit, with 4, 8 or 16 outputs per module. This arrangement is sometimes convenient very large distribution systems, where space is at a premium.

1.8 Power Supplies

The RR1110 series of 19" rack mounting units are usually powered from the mains supply and operate from 90-240 Vac (50-60Hz) and using switch mode converters. These supplies have proved highly reliable (>250,000 hours MTBF) but alternative linear DC supplies (24Vdc) with redundancy are available for systems where no-break operation is mandatory.

1.9 Heat Dissipation and Thermal Management

The amplifier is the main (only) heat generating component in the system and the supply is generally set to 800mA at 24Vdc (20W). The heat is conducted away through a substantial heat sink plate to the case providing a low thermal resistance from the heat source to the case.
The waste heat must be dissipated through the case to the circulating air in the rack.
Typically the difference between case temperature and surrounding air must be maintained greater than 5 degrees C.

The physical orientation of the unit is optimised for heat transfer but best practice is to limit the number of 19" 1U high units to five stacked with a 1U air gap both above and below.

4. Environmental Considerations

The RR1110 multicoupler contains no toxic materials except for a small quantity of beryllium oxide in the main transistors. Insulation is specified for low smoke and fumes.

The unit is CE marked and meets all the provisions of European Health and Safety regulations at current date.
Disposal at end of life or surplus to requirements should be in accordance with the local regulations on electrical waste (WEE Directive within EU) or the units can be returned to Raven Research for disposal for an additional cost, to be agreed before returning the unit(s).

5. Packaging - Size and weights, shipping weights

Qty	Article Weight	Packed Deadweight	Volumetric Weight
1	2.8kg	4kg	5.6kg
4	11.2kg	14kg	17kg