Radio Harmonic Power

in low power amateur radio handhelds

(tests conducted in August 2023)

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Executive Summary

Inexpensive amateur radio transceivers are in common use around the world. There is a perception that many, if not all such radios are non-compliant in relation to spurious emissions. The authors set out to test this using a Hewlett Packard 8920A RF Communications Test Set capable of testing 400 kHz to 1 GHz.

RF emissions were tested on the 2m amateur band and readings at the second and third harmonics were recorded.

The tests across a range of brands and models reveal that:

- All "name brand" radios were compliant, none were close to borderline.
- All radios from brands sold in Australia by Australian distributors were compliant.
- The Baofeng radios constitute the largest sample of the inexpensive radios, and of these 7 out of the 26 tested were compliant, 8 were non-compliant and a further 11 were borderline.
- The small sample size of the radios purchased online prevent conclusions being made about specific brands, however it is noteworthy that collectively about half were compliant.

There is an assumption that factory supplied equipment is fit for purpose and operates within regulations, but these tests show that this is often not the case. Radio amateurs today have access to a wide variety of transmitters which are often operated within that assumption. As a result, and despite readily having access to inexpensive and quality testing equipment, such transmitters are inadvertently operated outside the regulatory requirements.

Our findings show that any radio purchased from an Australian distributor appears to have passed the regulatory requirements and the adage that “you get what you pay for” bears out.

This report also includes a section on interpretation of results for those who would like to understand their personal test results.

Introduction

Radio transmitters are available across the world in a bewildering variety and price point. For years there has been an influx of cheap radios and the price conscious radio amateur community has embraced these new entrants with enthusiasm.

Several amateurs have observed that some of these radios are not performing within the specifications[1] outlined for amateur radio equipment by the International Telecommunications Union, the ITU, let alone more stringent requirements imposed by various jurisdictions[2].

Several tests have been conducted both formally and informally by individual amateurs[3] as well as organisations like the American Radio Relay League[4], the ARRL, the peak body for amateur radio in the United States.

As a result, an often repeated statement is that “cheap Chinese radios are non-compliant”.

Given that such radios are often a first introduction to the amateur radio hobby, the authors set out to test if this sentiment was universally applicable or not.

Summary of test equipment and setup

Testing was conducted using a Hewlett Packard 8920A RF Communications Test Set capable of testing 400 kHz to 1 GHz. Tests were performed using the RF In/Out port, rated at 60 Watts continuous power using 40 dB of attenuation.

Radio power output was measured on the “TX” screen, set to “Tune Mode: Auto”. Any frequency difference between the radio display and the test set was noted.

Power output at the fundamental, second and third harmonic frequencies were measured using the “SPEC ANL” screen. Frequencies were manually entered and make, model and power readings were manually recorded onto sheets of paper and later transcribed into a Google Spreadsheet for analysis. Radio owners were supplied with a copy of the measurements.

The majority of measurements were made on “testing day”, during the local Northern Corridor Radio Group annual HAMfest, held on Sunday, 20 August 2023 at the Cyril Jackson Recreation Centre. Visitors were encouraged to bring their handheld radio for testing purposes.

Visitors were encouraged to set their radio to the Australian 2m FM calling frequency of 146.500 MHz where possible, to disable any CTCSS or DCS tone and to disable any repeater offset.

Testing consisted of the following process:

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1 ITU specification which also includes examples on how to apply the rules: “Recommendation ITU-R SM.329-10” - “Unwanted emissions in the spurious domain” https://www.itu.int/dms_pubrec/itu-r/rec/sm/R-REC-SM.329-10-200302-S!!PDF-E.pdf

2 FCC specification has stricter requirements than the ITU and makes exceptions for equipment of different ages: https://www.govinfo.gov/content/pkg/CFR-2010-title47-vol5/pdf/CFR-2010-title47-vol5-sec97-307.pdf

3 Hayden VK7HH tests a UV5R3: https://www.youtube.com/watch?v=bQyyBnEzrY4

4 ARRL QST, November 2015 “ARRL Laboratory Handheld Transceiver Testing”: https://www.nf9k.net/wp-content/uploads/2016/05/ARRL-Lab-HT-Testing.pdf

- The antenna was removed and a 1 metre long coax patch lead was attached (including any adaptors to SMA if required). The patch lead was then connected to the HP Test Set.
- With the test set on the "TX" (transmitter test overview) screen, the transmitter was triggered and readings recorded.
- With the test set on the "SPEC ANL" (spectrum analyser) screen, for each of the relevant frequencies, the frequency was entered, the transmitter was triggered and readings recorded.
- The radio was disconnected.
- The recorded readings were transcribed onto a separate sheet which was provided to the owner of the radio.

Prior to testing day 16 tests were conducted to validate the process.

On testing day 54 tests were conducted.

Subsequent to testing day, 4 additional tests were made using the same process.

In all, 39 distinct models of radio were tested.

Notes

For several radios more than one test was conducted at different power levels or frequency ranges.

The test set has not been calibrated recently and the authors observed that there was a 3 dB difference between the total power reading on the “TX” screen when compared to the power reading on the “SPEC ANL” screen. Given that the readings of interest are relative, rather than absolute, this was not considered a factor in this report.

Classification (quantitative) of misbehaving radios and justification of classification

We used the Australian regulations for spurious emissions from radios to set the threshold for classification of a radio's performance, which are consistent with ITU guidelines. Specifically, for transmitters with power less than 500 Watts[5] spurious emissions must have a power level lower than the fundamental (in dB) defined by $43 + 10\log_{10}(P)$, where P is the power of the fundamental in Watts. For a 5 Watt radio, this formula yields 50 dB, hence the spurious emission limit is 5 Watt = 37 dBm - 50 = -13 dBm.

Given the measurement and calibration uncertainties of the test equipment noted above, we also define a less stringent threshold, relaxed by 6 dB[6]. This allows devices that have emissions that just exceed the limit to be classified as "borderline".

[5] From 500 Watts the emission requirement peaks at 70 dB.

[6] We have chosen 6 dB based on a 3 dB random measurement error and 3 dB to allow for a systematic error associated with any potential calibration errors.

Analysis

Chart 1 provides a summary of the radios tested by brand. The chart shows that we received a good sample covering "name brands" as well as new and inexpensive brands. In particular we received a good sample of Baofeng, Yaesu and Icom radios.

In Australia, the following brands are sold by Australian distributors: Icom, Yaesu, Wouxun, TYT. Other models are purchased via generic web retailers.

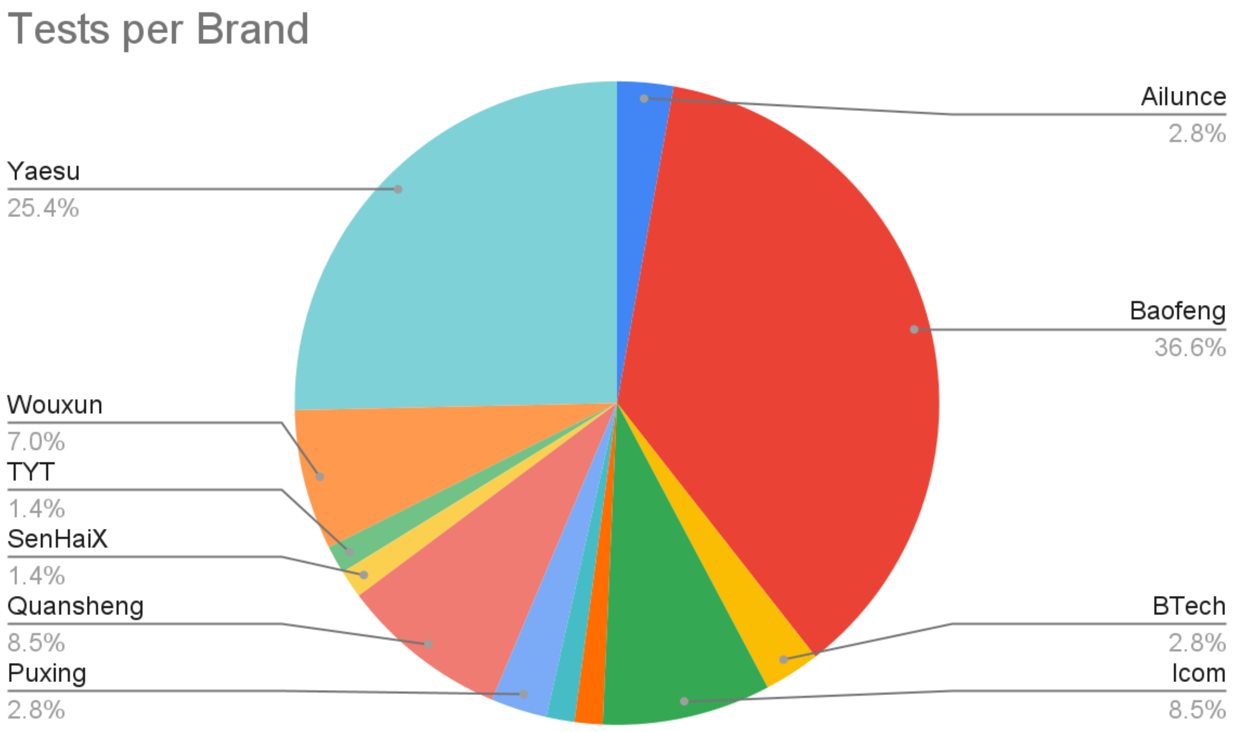

Chart 1: Breakdown of the number of tests conducted per brand.

Chart 2 provides a summary of the test results by brand, categorised into pass, fail and borderline.

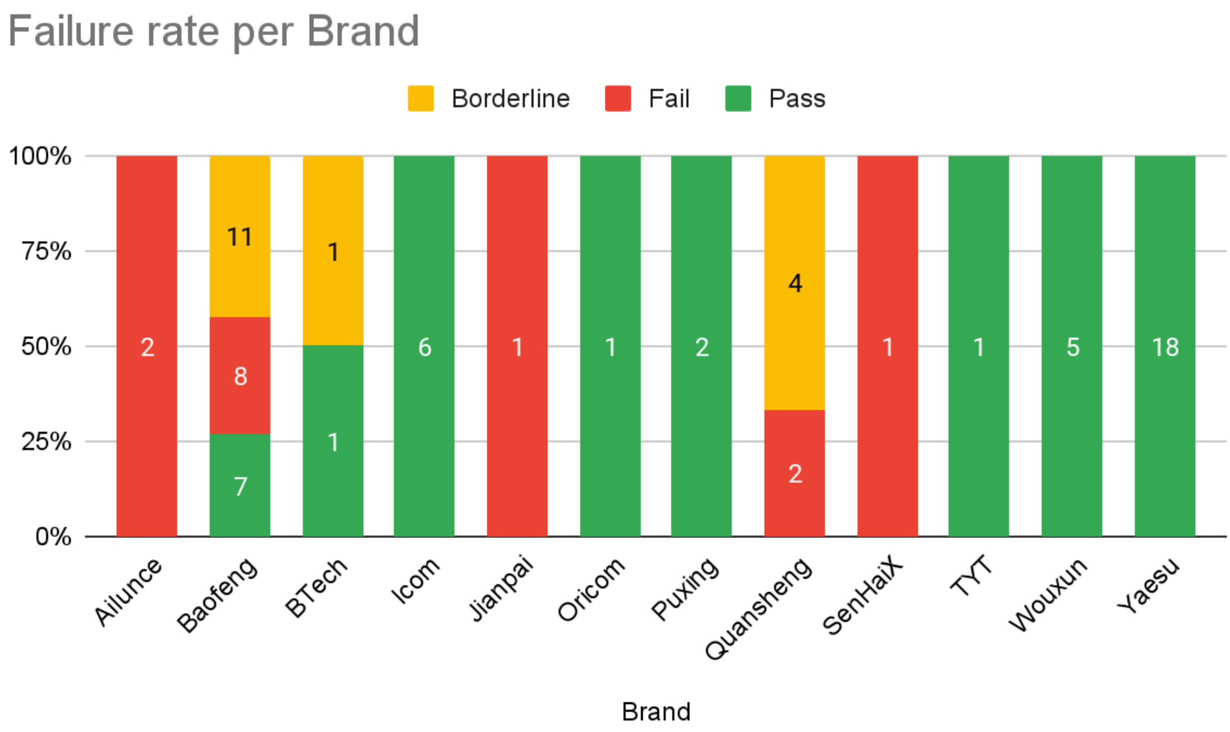

Chart 2: Breakdown of Pass / Failure and Borderline tests per brand.

We note the following:

- All "name brand" radios were compliant, none were close to borderline.
- All radios from brands sold in Australia by Australian distributors were compliant.
- The Baofeng radios constitute the largest sample of the inexpensive radios, and of these 7 out of the 26 tested were compliant, 8 were non-compliant and a further 11 were borderline.
- The small sample size of the radios purchased from online retailers prevent conclusions being made about specific brands, however it is noteworthy that collectively about half were non-compliant.

Examples of Spectrum Analyzer Screen

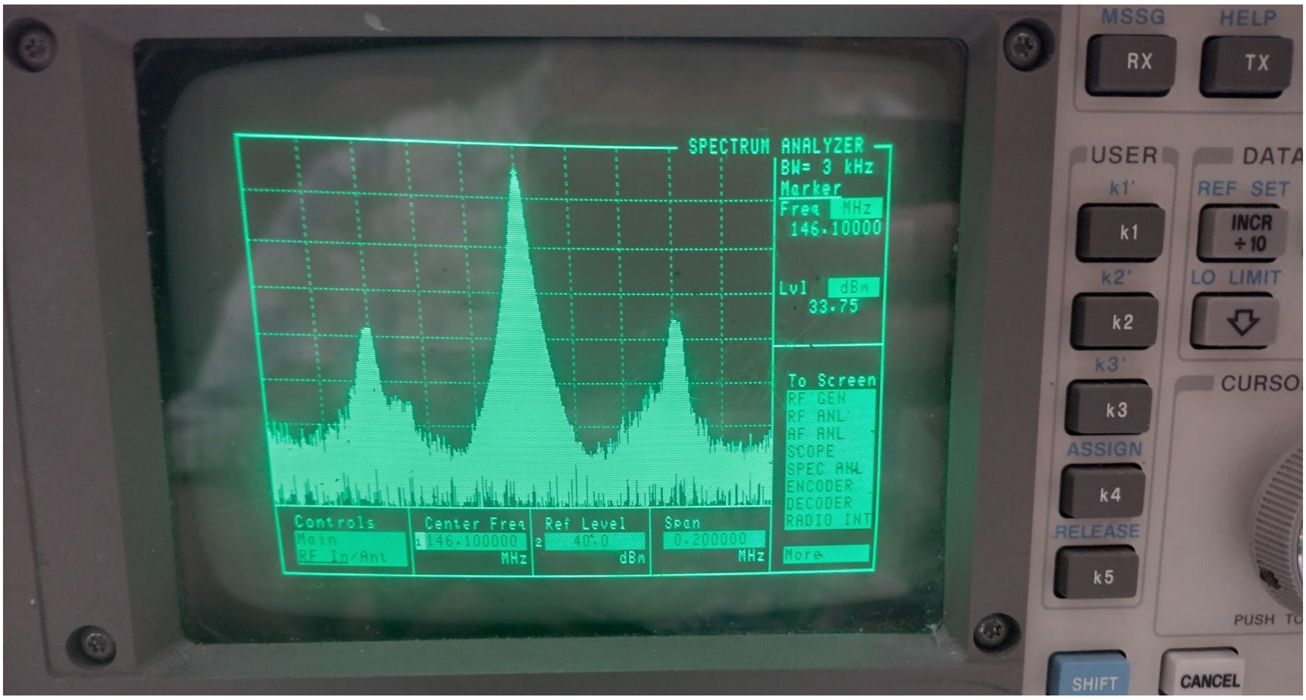

Image 1: This is an example of an FM transmitter that is creating spurious emissions.

Image 2: This is an example of an FM transmitter that is compliant.

Discussion

It is noteworthy that 5 of the Baofeng radios tested and the one Jianpai radio had second harmonics less than 20 dB below the fundamental, i.e. they are highly non-compliant. These radios are examples of the very poorly performing units, similar to those that have been highlighted in individual anecdotal cases. Based on our sample, nearly 20% of the Baofeng radios tested were so poorly performing, which is concerning.

There is an assumption that factory supplied equipment is fit for purpose and operates within regulations, but these tests show that this is often not the case. Radio amateurs today have access to a wide variety of transmitters which are often operated within that assumption. As a result, and despite readily having access to inexpensive and quality testing equipment, such transmitters are inadvertently operated outside the regulatory requirements.

Our findings show that any radio purchased from an Australian distributor appears to have passed the regulatory requirements and the adage that "you get what you pay for" bears out.

During the production of this report the authors received some uncorroborated commentary which on further examination appear to have merit. They are included here, without proof or reference, for potential further study.

It was suggested that some radios failed emission standards after suffering damage in the output filtering stages in some unspecified way. A cursory glance at a circuit diagram for one radio suggests that this is a plausible failure mode where a simple capacitor failure might cause a filter to fail without preventing the transmitter to operate. Further investigation might centre on how such a failure might occur and if such failures actually cause out of regulation behaviour.

Another suggestion was that some radios might use a specifically designed antenna to suppress the second harmonic. Given that some radios failed only on the second harmonic spurious emission requirement, but not the third, this seems plausible. The authors note that all tested radios had removable antennas and compliance is set at the transmitter output, not at the antenna output. It could be argued that if an antenna was not detachable, this construction might be construed to meet the emission requirements. It does raise a more interesting question, what is the impact of fitting aftermarket antennas to such radios in relation to their on-air behaviour?

Finally, during testing the authors were asked why we were not conducting deviation testing. The authors considered this as an option, but reached the conclusion that given the wide range of radios expected to be tested, there was no[7] single, or simple, way to conduct a standard test across all handsets. There is potential for exploring this further, especially since it’s clear from actual on-air use of these radios that deviation does not appear to be standardised across models or brands.

[7] Tests of this nature require that a known input generates a measured output. This means that each radio would need to be physically connected via its microphone input to the testing equipment. Making such an interface for one radio is feasible, but quickly becomes a project in itself when considering the variation in connectors, polarity, impedance, and potential microphone bias voltages.

Interpreting the results of a test

Visitors to "testing day" who offered their radio(s) for testing were supplied with a report card. To understand the results and determine if your radio is compliant with the regulations, we offer the following guide.

Please note that this is not a certification, the authors make no warranties, implied or otherwise, that the results are accurate in respect to your specific handset and we note that there is a 3 dB difference between the Power reading and the Primary output reading when both should be the same.

Given that the threshold value is calculated using the supplied power reading in Watts and the differences between the harmonics are measured in dBm from the same screen we have a high level of confidence that the results are representative.

For some radios, testing was conducted on the 70cm amateur band and given the maximum frequency of the testing equipment were only tested on the second harmonic.

For some radios, testing was conducted using several power levels and the results of the following will likely vary for each power level.

For some radios, testing was conducted on the 6m amateur band. This frequency is greater than 30 MHz specified in the compliance regulations and the following calculations also apply.

To determine compliance, calculate the following:

- Using the value in the Watts field, calculate the **compliance threshold** using the formula: $43 + 10\log_{10}(P)$
- Using the primary dBm reading, subtract the calculated threshold value to get the **maximum permitted harmonic level**.
- Using the measurements for the secondary and third harmonics and compare these to the maximum permitted harmonic level.
    - If both harmonics are **less** than the maximum permitted harmonic level, the radio is **compliant**.
    - If any harmonic is **greater** than the maximum permitted harmonic level, the radio is **non-compliant**.
    - If either harmonic is greater than the maximum permitted harmonic level, but the difference is less than 6 dB, we categorise the radio as borderline compliant.

Worked Examples

Below you'll find examples of test results and the method used to determine if the results indicate a radio that's compliant or not. Note that in this report we have created a relaxed category which we've called "borderline", describing results that do not meet the level of "compliant", but their non-compliance is less than 6 dB from the permissible level. This does not mean that a radio that is determined to be "borderline" is actually compliant, but within the margins of error introduced by our tests, it could be. In other words, do your own tests and draw your own conclusions.

Example of compliance:

This is an example of a compliant radio across both second and third harmonics.

Power (W)	Primary (dBm)	Second (dBm)	Third (dBm)
4.69	33.75	-27.79	-26.28

- Using the power reading (4.69 Watts), the threshold value is: 43 + 10 * $\log_{10}$(4.69) = 49.71 dB
- Subtract the threshold value from the primary output (33.75 dBm): 33.75 - 49.71 = -15.96 dBm
- The second harmonic (-27.79 dBm) is less than -15.69 dBm (by -11.83 dB)
- The third harmonic (-26.28 dBm) is less than -15.69 dBm (-10.32 dB)
- This radio is compliant for both harmonics.

Example of non-compliance:

This is an example of a non-compliant radio. The third harmonic is not compliant and the difference between compliance and non-compliance is greater than 6 dB, in this case, the difference is 10 dB.

Power (W)	Primary (dBm)	Second (dBm)	Third (dBm)
5.44	34.36	-23.00	-6.00

- Using the power reading (5.44 Watts), the threshold value is: 43 + 10 * $\log_{10}$(5.44) = 50.36 dB
- Subtract the threshold value from the primary output (34.36 dBm): 34.36 - 50.36 = -16.00 dBm
- The second harmonic (-23.00 dBm) is less than -16.00 dBm (by -7 dB)
- The third harmonic (-6.00 dBm) is greater than -16.00 dBm (by 10 dB, greater than 6 dB)
- This radio is non-compliant for the third harmonic and the difference is greater than 6 dB. This radio is non-compliant.

Example of borderline-compliance:

This is an example of a radio that is non-compliant on either harmonic, but the difference between compliance and not is less than 6 dB. We categorised this as a borderline compliant radio.

Power (W)	Primary (dBm)	Second (dBm)	Third (dBm)
4.73	33.30	-14.50	-12.30

- Using the power reading (4.73 Watts), the threshold value is: $43 + 10 * \log_{10}(4.73) = 49.75$ dB
- Subtract the threshold value from the primary output (33.30 dBm): 33.30 - 49.75 = -16.45 dBm
- The second harmonic (-14.50 dBm) is greater than -16.45 dBm (by 1.95 dB, less than 6 dB)
- The third harmonic (-12.30 dBm) is greater than -16.45 dBm (by 4.15 dB, less than 6 dB)
- This radio is non-compliant for both harmonics, but the difference is less than 6 dB, this radio is borderline compliant.