Output Harmonics – HF Transmitter Fault Analysis

A survey of our members (North Cheshire Radio Club) in 2017 showed that no one could recall checking the output harmonics of their transmitters. I expect we are no exception in this respect, so why hasn't it brought Ofcom knocking on the door?

In the early days of radio, the by product of the valve transmitter output stages being tuned and loaded was the attenuation of the second and third harmonics by at least 40dB. This was acceptable because the amateur bands were harmonic related. Better attenuation has lead to none harmonic related bands of 30m, 17m & 12m being added (WARC bands) in the 1980s.

It has been suggested that in practice harmonics have not been a problem because a correctly designed transceiver would only produce excessive harmonics if the output stage was over driven or had a biasing fault. This would be revealed by the spreading bandwidth of the signal which is relatively easy to spot. A component failure in the final stage of the transmitter and its low pass output filter could reduce the attenuation of the harmonics but would most likely alter the loading reducing the output power or result in catastrophic failure. In either scenario you would notice something was not right! Also the ATU could provide additional attenuation of the harmonics and their poor match to the antenna would further reduce the harmonic energy radiated.

In order to test the above hypothesis a fault analysis was carried out using a simulation of the output stages of a typical transmitter. The Kenwood TS-440 was chosen and modelled using LTspice – see Fig.1.
The circuit was stripped down to the basics, the following should be noted :-

- The simulations were run for 100 Watts output at 14MHz.
- The fundamental voltage and the harmonics were measured across a 50 Ω load, no ATU was used.
- There was no spice model available for the output transistors (2SC2879) which only had basic data sheets posted on the Internet. A generic transistor model was therefore used with the DC gain set to 100 (BF). The data was added twice to the schematic so that the effect of variations between the two transistor characteristics could be explored.
- The service manual gave values for the resistors and capacitors, but there were none for the inductors or the turn ratios for the matching and feedback transformers.
    - The transformers were therefore based on the Motorola application note AN-762 for linear amplifiers.
    - The Cauer type low pass filter was derived from first principles using the Qucs filter design tool. The resulting capacitor values are similar but not identical to those in the TS-440 circuit.
- The VSWR circuit was incorporated as a check on the output matching circuit. The TS-440 circuit arrangement was used but the values were based on the bi-directional inline wattmeter by David Stockton G4ZNQ. Note: The TS-440 uses the reflected voltage signal to control the ALC to protect the transmitter from miss-matched antenna impedance by reducing the drive signal, but it does not protect against miss-matches caused by faults in the low pass filter circuit etc.

Rules used for the fault analysis :-

- Only one component fault is considered at a time, it being assumed that the failure will be revealed before another fault could occur, or has only a marginal effect on the harmonics.
- Resistors – increase in value $\rightarrow$ open circuit.
- Capacitors – reduce in value $\rightarrow$ open circuit or short circuit.
- Inductors – reduce in value $\rightarrow$ open circuit or short circuit.

Summary of the Results

Out of the faults that would cause increases in the harmonics :-

- 20% would result in failure due to over current in the output transistors.
- 20% would cause failure due to over voltage of the output transistors.
- 20% would result in a very noticeable loss of output power and high losses in the transistors causing rapid thermal cut out.
- 40% increased the level of the harmonics, but the worst case was still 54dB below the full power fundamental, and therefore only had a marginal effect. These components were ahead of the low pass filter section and were there to improve the linearity of the amplifier or to protect the transistors from the stray inductance of a real circuit.

Figure 1 : Ltspice model of the TS-440 Transmitter Output stage.