Harmonic-Free QRP?

Avoid an FCC pink slip by measuring second-harmonic power with the ZS6UP reactance load.

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Like many others who like to keep their hands busy and who like the smell of solder, I also pass my time by building simple receivers[1] and QRP transmitters. I am always worried that the output filter of the QRP transmitter is not working well and that I put out too much second-harmonic power. It is no use listening to the second harmonic on the station receiver—it always sounds strong and no real idea can be formed of the strength in relation to the primary emission.

Of course, like most other hams, I don't own a spectrum analyzer to determine the harmonic output, but through the years I developed first a simple relative method and then a somewhat more sophisticated method of determining second-harmonic power. Of course, there are higher harmonics also, but in this discussion I shall stick to the second harmonic. In this article, I concentrate on 40m power from an 80m QRP transmitter.

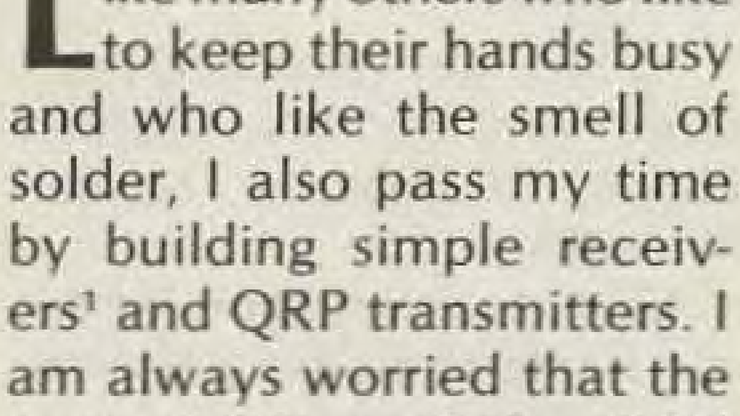

Fig. 1. QRP transmitter hooked through directional wattmeter or swr meter to 80m antenna.

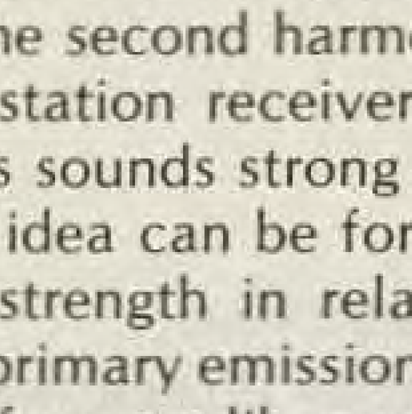

Fig. 2. Special dummy load.

Simple Relative Method

I know that on my 80m antenna there is a frequency spot where the swr is exactly 1:1. So, when I finish building a QRP transmitter, I tune it to this frequency and hook it through a directional wattmeter (a simple swr meter will also do) to the 80m antenna (see Fig. 1). As the swr is 1:1 on 80m, there will be no reflected power on 80m. All the reflected power is thus on 40m or higher frequencies.

All that I then do is to tune the output stage and filter of the QRP transmitter so that this reflected power is at a minimum. Then I check the forward power again to see if it hasn't dropped too much. After this I am pretty certain that almost all of the power going out is on 80m.

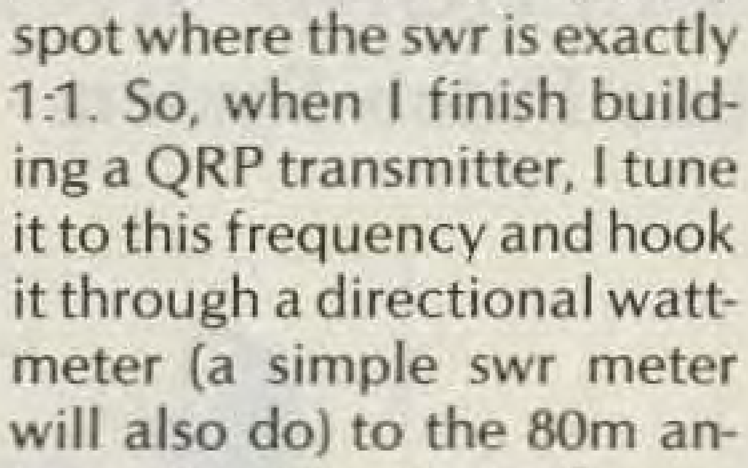

Fig. 3. Construction of special dummy load.

More Sophisticated Method

In the first-mentioned method, no idea can be formed of the ratio of 80m to 40m power, but it can be calculated if the swr on 40m on the 80m antenna is known exactly. (Somehow it doesn't appeal to me to put all these signals on the air for testing purposes only, even if I announce my callsign every time.) So I started thinking of a type of dummy load which has an swr equaling one on 80m and a much higher (but known) swr on 40m. Such a dummy load is shown in Fig. 2.

In Fig. 2, the 51-Ohm resistance, R, has more or less the same value as the impedance of 52-Ohm coaxial cable (Z_0). On 80m, $X_L = X_C$ and thus cancel out where X_L = inductive reactance of inductor L (Ohm) and X_C = capacitance reactance of capacitor C (Ohm).

On 40m, $X_L \neq X_C$, which causes a certain swr on 40m. See box for theoretical calculations.

In practice, we choose $R = Z_0$ and for 80: $X_L = X_C$. If these values are put in Equation 4, the swr = 1, as it should. If for 40m X_L is not equal to X_C, the swr is a value greater than one. We can now either choose a value for the swr and calculate $X_L - X_C$ or choose a value for $X_L - X_C$ and calculate the swr on 40m.

I chose the latter route and put $X_{L40} - X_{C40} = 100$, where the subscript 40 means 40m and later on the subscript 80 will mean 80m. Put in Equation 4, we get $swr_{40} = 5.83$.

So, if we now know the swr on 40m how can we apply it to find E_f on 40? From Equation 3 we can write Equation 5: $E_{f40} = [E_{r40}(swr_{40} + 1)^2]/(swr_{40} - 1)^2$. We also know that as $swr_{80} = 1$, there is no reflected power on 80m. So all the reflected power is due to 40m (or higher) harmonics. Total forward power E_{ft} is equal to $E_{f80} + E_{f40}$. For the measurement and calculation of E_{f40}/E_{f80}, we go about as follows:

Put the directional wattmeter in the line between the transmitter and the special dummy load. Read the forward power, which is $E_{ft} = E_{f80} + E_{f40}$. Read the reflected power, which is equal to E_{r40}. From the above equation, calculate E_{f40}. Then $E_{f80} = E_{ft} - E_{f40}$, and the ratio E_{f80} to E_{f40} can be calculated. An example later on will make it clearer.

To calculate values of L and C in Fig. 2, we can write the following equations: $X_{L40} - X_{C40} = 100$ (chosen value); $X_{L80} - X_{C80} = 0$. Thus, for 40m:
$2\pi \times 7 \times 10^6 \times L \times 10^{-6} - 1/(2\pi \times 7 \times 10 \times C \times 10^{-12}) = 100$, and for 80m:

$2\pi \times 3.5 \times 10^6 \times L \times 10^{-6} - 1/(2\pi \times 3.5 \times 10 \times C \times 10^{-12}) = 0$.

Here we have two equations with two unknowns, and from simple arithmetic we get L = 3.03 microhenrys (μH), and C = 682 picofarads (pF).

(By the way, we don't need the actual X values, but here they are as a point of interest: $X_{L80} = X_{C80} = 66.6$ Ohms, $X_{L40} = 133.3$ Ohms, and $X_{C40} = 33.3$ Ohms.)

Construction

Construction is very, very simple. Using the well known formula for coils (in all handbooks), I wound a coil, L, with value 3.03 μH. For the capacitor, C, I put 470 μF in parallel with a variable, connected it to my capacitance meter, and turned the variable until total capacitance was 682 pF. If you don't have a capacitance meter, just put a few capacitors in parallel to get 682 pF. For resistor R use 51 Ohms. (47 or 56 Ohms will also do; 5 Watts; carbon.) Put the items together as in Fig. 3.

To test the contraption, I tuned my station transceiver to as low an output as possible. I switched to 3.5 MHz and connected it to the special dummy load through the directional wattmeter/swr meter. The swr was exactly 1.0. Then I tuned to 7 MHz, and lo and behold, the swr read 6.0, very near to the theoretical value of 5.83. I began to get the feeling that this thing was going to work!

Application

After the test, I removed the station transceiver and hooked on my latest 80m QRP transmitter. The directional wattmeter read: forward power, 22 Watts. Thus, $E_{ft} = E_{f80} + E_{f40} = 22$ Watts. I switched to reflected power, and the meter read 1 Watt.

Thus, $E_{r40} = 1$ Watt; from Equation 5: $E_{f40} = [1 \times (5.83 + 1)^2]/(5.83 - 1)^2 = 2.0$ Watts.

THEORY

Here are some equations for the calculation of swr—see reference 2.

(1) Swr = $(1 + p)/(1 - p)$, where p = reflection coefficient; and

(2) $p = \sqrt{E_r}/\sqrt{E_f}$, where E_f = forward power (Watt) and E_r = reflected power (Watt).

(3) Thus swr = $(\sqrt{E_f} + \sqrt{E_r})/(\sqrt{E_f} - \sqrt{E_r})$.

In terms of impedances, the complete equation for swr is

(4) Swr = $(\sqrt{(R + Z)^2 + (X_L - X_c)^2} + \sqrt{(R - Z_o)^2 + (X_L - X_c)^2})$ divided by $(\sqrt{(R + Z_o)^2 + (X_L - X_c)^2} - \sqrt{(R - Z_o)^2 + (X_L - X_c)^2})$.

(5) $E_{f40} = [E_{r40}(swr_{40} + 1)^2]/(swr_{40} - 1)^2$.

Thus, $E_{f80} = E_{ft} - E_{f40} = 22 - 2 = 20$ Watts; $E_{f80}/E_{f40} = 20/2 = 10 = 10$ dB.

Thus, the 40m signal is only 10 dB lower than the 80m signal. This is not good enough, and I now know I'll have to work again on the output stage and low-pass filter of my QRP transmitter.

Conclusion

I have described a method and simple device with which one can ascertain the second harmonic power of a home-built transmitter. I am sure that with a little thinking it can be extended to measure the higher harmonics, also. Is there an ingenious reader who will attempt this, without nearing the complexities of a real spectrum analyzer? ■

References

1 "Direct Conversion Lives," Mike van der Westhuizen ZS6UP, *73 Magazine*, November, 1980.

2 *ARRL Antenna Book*, American Radio Relay League, Newington, Connecticut.