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# The "True" TLT H-mode Mixer

*Transformers are important components in H-mode mixers, but conventional transformers introduce limitations. Here is a novel H-mode mixer configuration that uses transmission line transformers (TLTs) for improved performance.*

In 2003 I built the first version of my transceiver with DSP IF processing.[1] I've used it since then and I have made many improvements (both in hardware and software). In 2008 I realized that I had to design a different hardware platform to implement all my new ideas. I wanted flatter IP3 values across the bands and better NF. The goal was IP3 at or above +40 dBm on all HF bands with the lowest possible NF (without compromising IP3 performance). So I started a new project and needed a new mixer to go along with it.

The H-mode mixer[2, 3] has become a standard in high performance HF front ends[4] in recent years. It is simple, inexpensive and performs exceptionally well. I've enjoyed good results using a single balanced H-mode mixer variant in my T03DSP transceiver and that was my inspiration to pursue the enhanced H-mode mixer described here.

Martin Bakker, PA3AKE,[5] did excellent research on high-performance H-mode mixers. His research demonstrated that the performance of an H-mode mixer greatly depended on two key components: switches and transformers.

I was limited to FST3125 switches, T4-1 and homemade transformers in my experiments. I had made two test H mode mixers (one using T4-1 transformers and another one with homemade conventional transformers) and measured their IP3 performance. Both mixers showed substantial IP3 drops with increasing operating frequency (+35 to +40 dBm on 160 meters, dropping to +25 to +30 dBm at 10 meters). I was disappointed with such results, so I started to look for improvements.

[1]Notes appear on page 15.

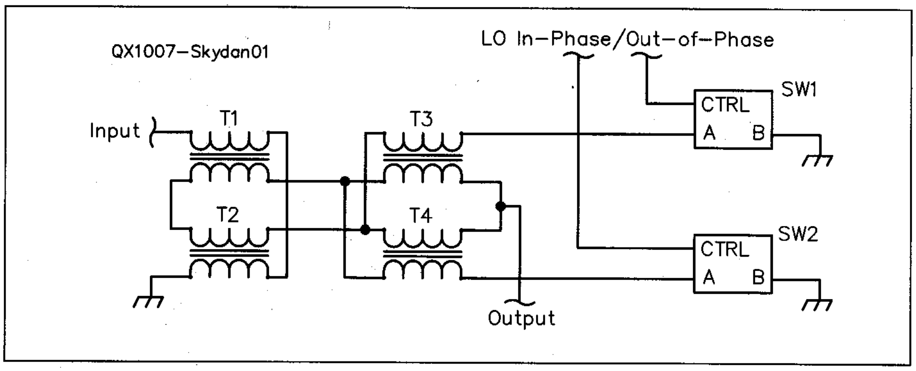


**Figure 1 — RZ4HK's TLT H-mode mixer.**

## RZ4HK's TLT H-mode Mixer

During the Radio Communication 2007 design contest in Moscow (sponsored by the Suntel Corporation), Gennady Bragin, RZ4HK, demonstrated his transmission line transformer (TLT) H-mode mixer. See Figure 1.

He claimed that it was better than H-mode mixers that relied on conventional transformers, particularly in terms of broadband and intermodulation performance. But my tests seemed to show that RZ4HK's approach was really no better than designs that used conventional transformers. (Actually, I was able to obtain good numbers on one band, but not over the entire HF spectrum.)

After further analysis of RZ4HK's TLT H-mode mixer I realized that there was a flaw. Look again at Figure 1. During each half of the LO cycle we have an open line (T3 or T4), which is connected in parallel to the input transformers. This introduces additional parasitic capacitance and hampers wideband performance.

To craft a real high-performance TLT H-mode mixer, we must avoid configurations that create open lines in this fashion. The TLTs should operate without useless windings/lines that introduce parasitic, reactive loading. Otherwise we compromise the TLT's main advantage — its broadband performance.

## Designing the "True" TLT H-mode Mixer

I started to think about a TLT H-mode mixer design that could maximize its performance while reducing the number and types of transmission lines.

A single balanced "true" TLT mixer is shown in Figure 2. It consists of the Guanella 1:1 TLT (T1) and the Ruthroff 4:1 TLT (T2).[6]

The principle of operation is shown in

Figure 3. When switch S1 is closed and S2 is open, transformer T1 will introduce an additional 180° phase shift (Figure 3A), compared to when S1 is open and S2 is closed (Figure 3B). In the latter case T1 will act as just a piece of matched TL. As we can see, alternating between the two switching configurations effectively results in 180° signal phase rotation. There are no open lines and all transformers work in their usual modes during the both phases of the LO signal. Such a TLT configuration provides a 4:1 impedance transformation, so we will have a 12.5 Ω output impedance for the 50 Ω input, 25 Ω output for the 100 Ω input and so on.

Now, let's move to the double-balanced variant. We need two mixers fed with out-of-phase signals and a balanced-unbalanced transformer at the output.

The out-of-phase input signals can be easily obtained at no cost; we can just connect two identical mixers (Figure 2) in parallel and twist the input lines on the one of them (Figure 4). The usual Guanella 1:1 balun transformer is used to combine the output of the two mixers and convert the balanced output to an unbalanced one. As we can see, only five simple TLTs were needed for a double balanced "true" TLT H-mode mixer and only 100 and 50 Ω TLs were used.

The principle of operation is shown in Figure 5 (A and B). The double balanced configuration retains all the advantages of the single balanced variant (no open TLs) and introduces even more. The mixer now has the same input and output impedances. It is possible to compensate for minor imbalances in the T1/T3 transformers by using units with closely matched characteristics.

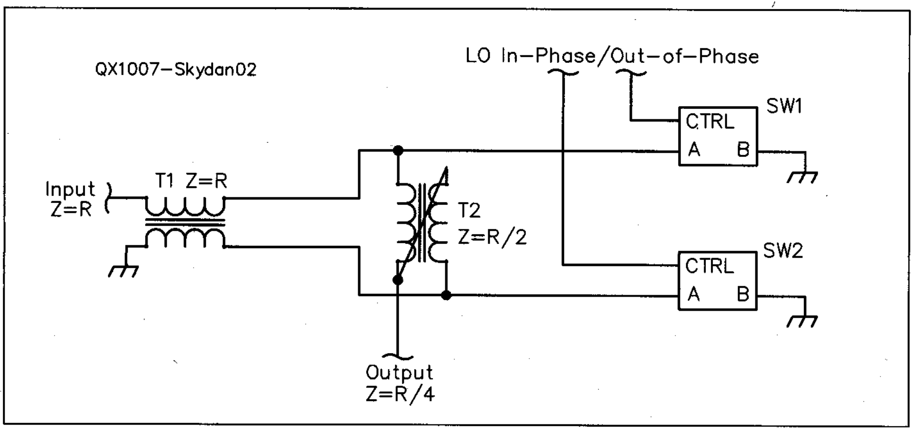


**Figure 2 — The single-balanced "true" TLT H-mode mixer.**

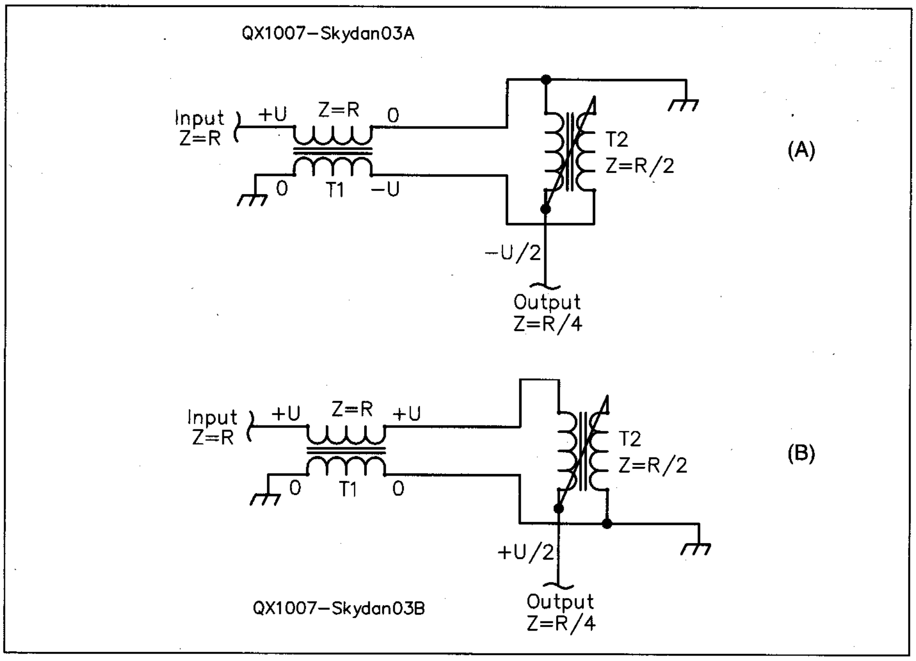


**Figure 3 — The operating principal of the single-balanced "true" TLT H-mode mixer.**

**Table 1**
**"True" TLT Mixer Conversion Loss (CL, dB)**

| *Band (meters)* | *160* | *80* | *40* | *20* | *15* | *10* | *6* |
|---|---|---|---|---|---|---|---|
| | 4.7 | 4.8 | 4.8 | 4.8 | 4.9 | 5.0 | 5.3 |

## The Prototype

An idea can certainly look good on paper, but the real proof is when you actually build the hardware and take measurements.

The first things I needed to make were the TLTs. To do this I needed 100 Ω and 50 Ω TLs. I decided to use twisted wire lines, but the available reference data needed to make the line with the required impedance was not consistent.[7, 8] I wanted to be sure the TLs had the required impedance, so, I used my RLC meter (it is able to measure inductance down to 1 nH and capacitance down to 0.01 pF) to measure the inductance and the capacitance of the lines and calculated line impedance using the following formula:

$$Z = \sqrt{\frac{L}{C}}$$

After spending some time twisting different wires, I finally made TLs with the necessary impedances and then subsequently wound the transformers. Two test configurations (I just assembled the transformers in configurations shown in Figure 5) were assembled and tested with the network analyzer before soldering the transformers on the mixer board. I was satisfied with the results; the combined insertion loss of the five-TLT system was less than 0.3 dB at 30 MHz and approximately 0.5 dB at 100 MHz. I was unable to find any imbalances between the two configurations. It was time to assemble the mixer and test it.

The mixer schematic is shown in Figure 6. I used FST3125 switches with a 6 V power supply. The assembled RF unit, which uses the "true" TLT H-mode mixer, is shown in Figures 7 and 8.[9]

The transformers were wound on K10x6x5 400HH ferrite cores (10 mm outer diameter, 6 mm inner diameter, 5 mm height, 400 permeability). The T1 and T5 transformers contain 14 turns of 0.25 mm diameter twisted silk-lacquer-insulated wire (TL Z = 100 Ω). T2, T3 and T6 were made with

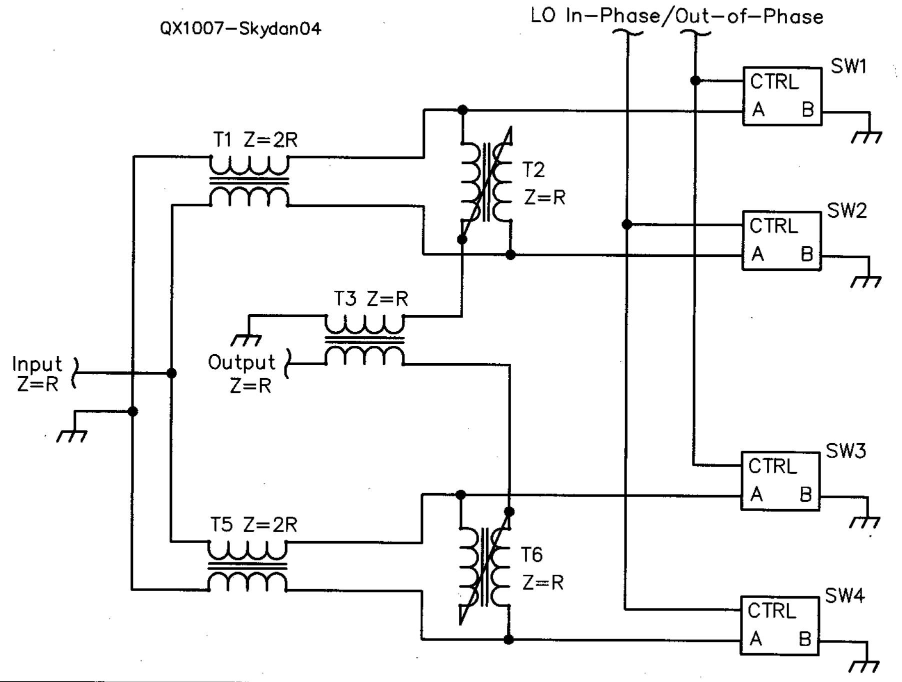


**Figure 4 — The double balanced "true" TLT H-mode mixer.**

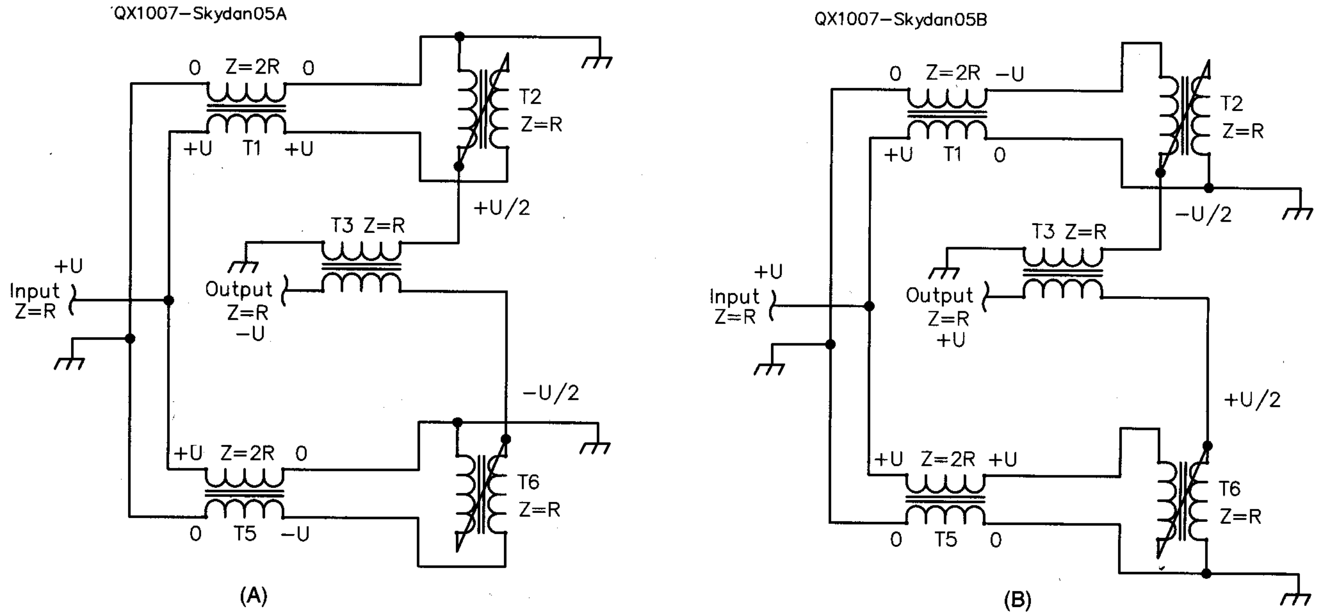


**Figure 5 — The operating principal of the double balanced "true" TLT H-mode mixer.**

**Table 2**
**"True" TLT Mixer IP3 by Band (meters)**

| | *160* | *80* | *40* | *20* | *15* | *10* |
|---|---|---|---|---|---|---|
| IP3 (two test signals $F_{in}$ – 20 kHz & $F_{in}$ – 40 kHz, 0 dBm), dBm | 46.9 | 43.2 | 41.6 | 39.4 | 37.2 | 37.6 |
| IP3 (two test signals $F_{in}$ – 20 kHz & $F_{in}$ – 40 kHz, –5 dBm), dBm | 45.1* | 43.3 | 41.4 | 39.2 | 37.0 | 37.2 |
| IP3 (two test signals $F_{in}$ + 20 kHz & $F_{in}$ + 40 kHz, 0 dBm), dBm | 45.2 | 43.4 | 42.0 | 39.3 | 37.8 | 38.1 |
| IP3 (two test signals $F_{in}$ + 20 kHz & $F_{in}$ + 40 kHz, –5 dBm), dBm | 47.1* | 43.4 | 41.9 | 39.0 | 37.6 | 37.6 |
| IP3 (minimal), dBm | 45.1 | 43.2 | 41.4 | 39.0 | 37.0 | 37.2 |

* - measurements were noise limited

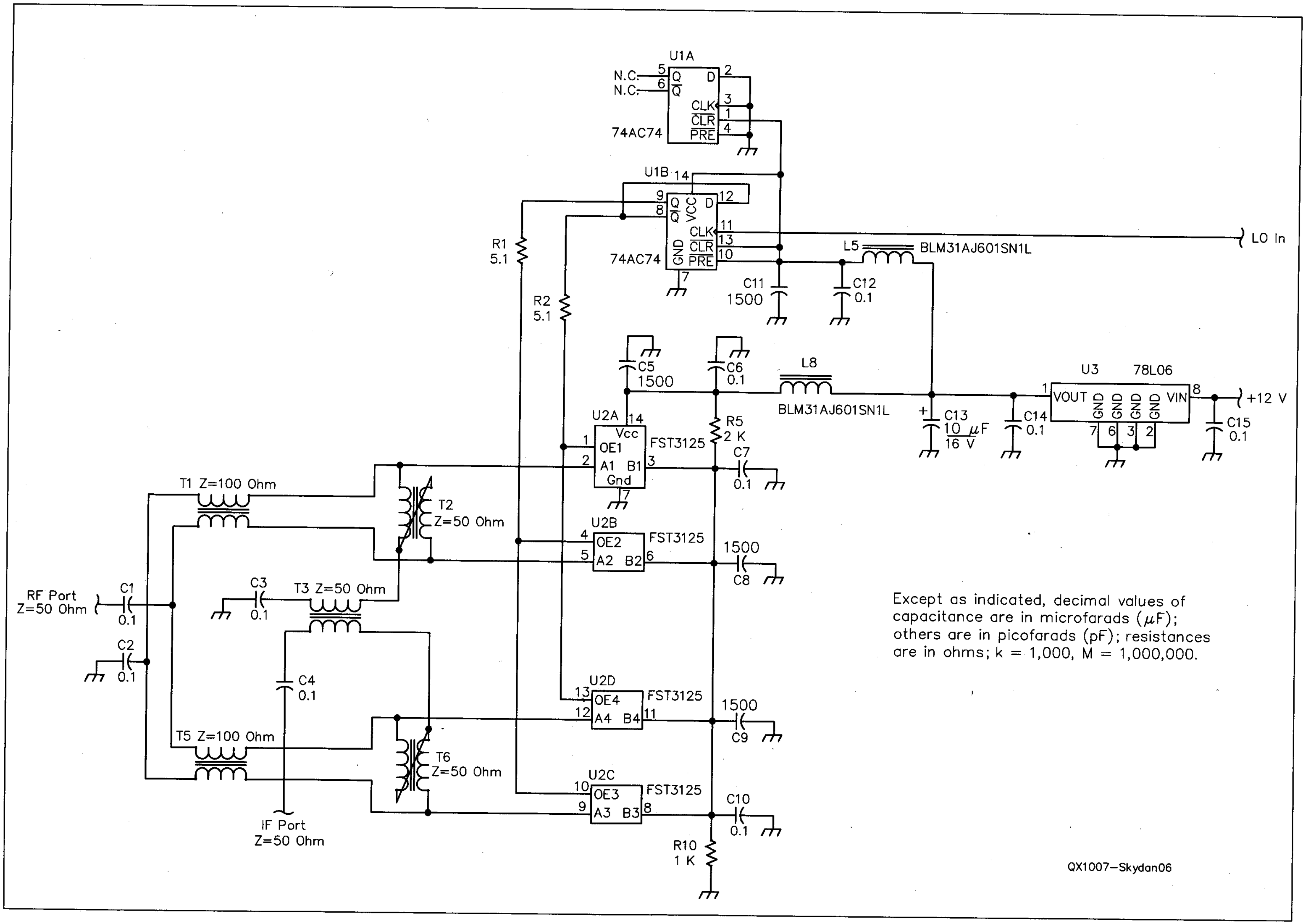


**Figure 6 — The "true" TLT H-mode mixer schematic diagram.**

10 turns of 0.35 mm diameter twisted lacquer-insulated wire (TL Z = 50 Ω).

## Results

I measured the conversion loss (CL), IP3 and isolation of the mixer. The CL and IP3 results are shown in Tables 1 and 2. The RF-IF isolation was better than 46 dB (the worst case result on 10 meters; there is no balance adjustment). The residual LO voltage at the RF mixer port was –53 dBV on 10 meters (35 MHz LO frequency), improving with an LO frequency reduction to –68 dBV on 160 meters (7 MHz LO frequency).

The mixer showed its best IP3 performance (among the alternatives measured in my lab) over the whole HF range. The FST3125/T4-1 mixer showed substantial IP3 drop to +25-30 dBm on 10 meters.

Another important feature of this mixer is that it is much less sensitive to the switch biasing voltage. (After a test of the biasing voltage influence I just set the biasing point to 1/3 $V_{cc}$, the center of the linear portion of the FST3125 switch transfer function). The T4-1 variant needed biasing adjustment on a per-band basis. Also, the "true" TLT H-mode mixer has much better IP3 amplitude law behavior and is less sensitive to termination quality. (I used the simple diplexer shown in Figure 9 between the 4-pole crystal filter and mixer, and managed to achieve front end IP3 performance at or above +40 dBm.)

## Conclusions

I have presented a novel configuration of the H-mode mixer that makes use of TL transformers. This mixer has definite advantages over those designed with traditional transformers. It provides better broadband (both IP3 and insertion loss) performance. It has the potential to obtain better linearity and less conversion loss since the flux is effectively cancelled out in the transformer

Figure 7 — The top side of the RF block.

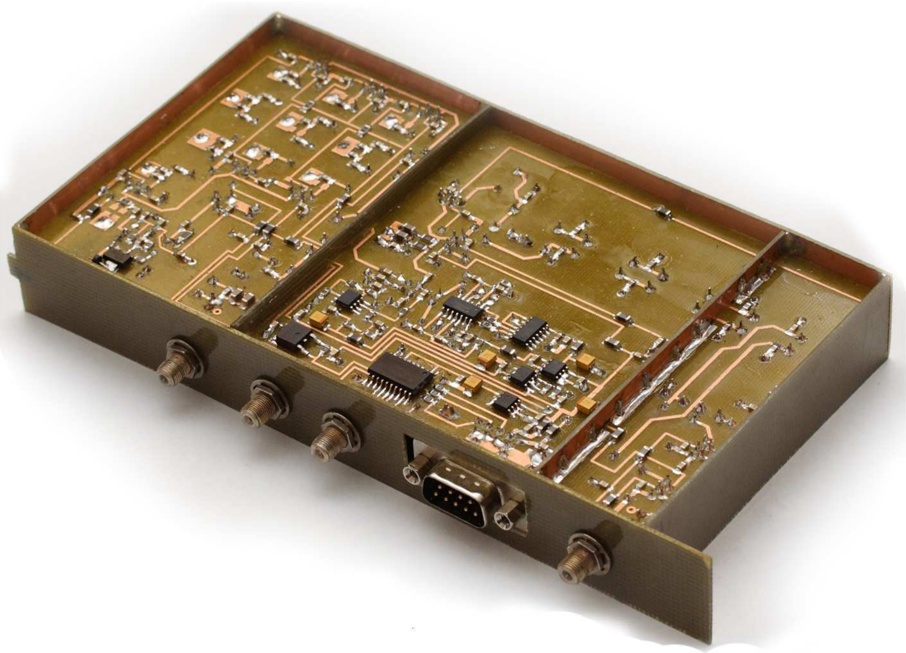

Figure 8 — A bottom-side view of the RF block.

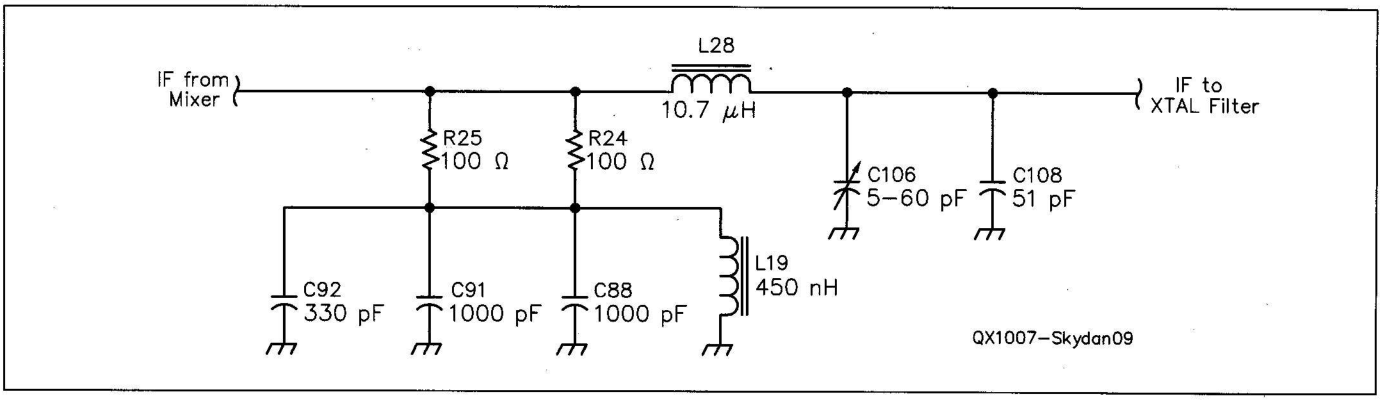


Figure 9 — The crystal filter matching network.

cores; the linearity of the "true" TLT H-mode mixer is determined by the switches alone. It is much cheaper and easier to obtain good results when using homemade transformers. TLTs are usually much less sensitive to the core material and provide more stable results when they are homemade with "primitive" technology compared to the conventional transformers.

The mixer performance numbers might be better if the proper termination is used (two hybridized crystal filters with a diplexer should do the job), but even with the simple termination I used, the results satisfy my requirements.

I think the mixer can be successfully used on VHF as well. The transformers are not the factors that limit broadband performance. Of course, we will need to solve the fast-switching problem at VHF; fast GaAs transistors might be the right choice.

*Oleg Skydan, UR3IQO, was born in Kramatorsk, Ukraine in 1978 and graduated with a Masters degree in Computer Science from the Donetsk Artificial Intelligence Institute. He obtained his Amateur Radio license in 1994 and began experimenting in transceiver and antenna design. In addition to his innovative T03DSP transceiver that debuted in 2003, Oleg has begun designing and building its successor, the Neon (***http://neon.skydan.in.ua***).*

## Notes


[1] Oleg Skydan, UR3IQO, "T03DSP," **http://t03dsp.skydan.in.ua**.

[2] Colin Horrabin, G3SBI, "G3SBI's High Performance Mixer," Technical Topics, *RadCom*, Oct 1993.

[3] Colin Horrabin, G3SBI, "G3SBI's H-Mode FST3125 Mixer – Constructional Details," Technical Topics, *RadCom*, Sep 1998.

[4] Colin Horrabin, G3SBI, Dave Roberts, G8KBB, and George Fare, G3OGQ, "The CDG2000 HF Transceiver," *RadCom*, June-Dec 2002.

[5] Martin Bakker, PA3AKE, "H-Mode Mixer Frontend," **www.xs4all.nl/~martein/pa3ake/hmode/index.html**.

[6] Jerry Sevick, W2FMI, *Transmission Line Transformers*, Fourth Edition, Noble Publishing Corporation, 2001.

[7] S.G. Bunin, L.P. Yailenko, *Spravochnik Radiolubitelja-Korotkovolnovika* (HF Amateur Radio Handbook), Kiev, Tehnika, 1984.

[8] Eric Tart Red, *Arbeitsbuch für den HF-Techniker: Daten, Fakten, HF-Grundshaltungen*, Franzis-Verlag GmbH, München, Germany, 1986.

[9] The details of the RF unit design can be found at the RF unit page on the Neon Web site: **http://neon/skydan.in.ua/RF.php**.


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