A Doubly Balanced "H-mode" Mixer for HF

Here's the latest on high-level switching mixers.

By Sergio Cartoceti, IK4AUY

RF Mixer Parameters: *IIP3*, *G*, Port Isolation

If you have a home-built receiver or transceiver for the amateur bands—or even manufactured equipment—that has proven weak in the front end, this article is for you. You could consider adding a band-pass filter at the input, which is desirable[1] for second-order IMD protection; but it will not necessary help the third-order IMD, measured as third-order intercept point or *IP3*. That is the figure of merit you would want as high as possible to avoid *in-band* third-order IMD problems. You could also plan to replace diodes having poor second- and third-order behavior with better PIN diodes at the input/output switching points in the front end, increase the current through them or use relays. Yet there are also RF mixers at each conversion.[2] Input *IP3* or *IIP3*, can be seen as a cumulative figure, in-volving all stages in a receiver; or measured in a single stage, such as for a mixer device alone.[3]

You would desire a receiver cumulative noise figure (*NF*) as low as practically possible. Observing the values we could get for these two parameters in an active device like a preamplifier, with a gain *G*, we think about them as tradeoffs because it is difficult to maintain low *NF* and high *IIP3* together. We need to measure the impact on a receiver's noise-floor performance.

Wes Hayward, W7ZOI, describes a figure of merit for receivers named *Receiver Factor* or *RF = IIP3 – NF*. The most important equation in a receiver that relates noise floor to *NF* is:

$$Noise\,Floor\,(\text{in dBm}) = -174 + 10\log(BW) + NF \qquad (\text{Eq 1})$$

where
  BW = bandwidth, in hertz.
  NF = noise figure, in decibels.
  Noise floor has been alternately called "MDS (minimum discernable signal), the input signal of a generator that will cause the output power to increase by 3 dB...."[4] as per

[1]Notes appear on page 32.

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ARRL Laboratory test procedures.

So we try our best to achieve good values in every stage as required for desired system performance. Wonderful software tools for system evaluation are available, such as in *Experimental Methods in RF Design* (ARRL) or in Agilent software *APPCAD*—this one is freely down-loadable from the Web.[5]

When we evaluate a mixer, we may measure third-order IMD at the output and gain (a passive mixer has a loss, so it is a negative value for *G*) and then we calculate *IIP3*:

$$OIP3 = P_{out} + \frac{IMD3}{2} \qquad \text{(Eq 2)}$$

where
P_{out} = power in each of two tones in decibels relative to a milliwatt,
IMD3 = decibels relative to the power in each tone.
Calculate *IIP3* using:

$$IIP3 = OIP3 - G \qquad \text{(Eq 3)}$$

where *IIP3* and *OIP3* are in decibels referenced to a milliwatt, *G* is in decibels (minus sign for loss).

Another important parameter is *port isolation* referred to the IF port. We need to measure LO-to-IF and RF-to-IF isolation in decibels. More isolation is better. Don't forget isolation at the LO-RF port.

High-Level H-mode Mixers in the Literature

The ARRL Handbook (2004, p 15.29) has a good concise definition of this H-mode term used in an RF-mixer context. Before you call for a paternity test on this mixer, I had better relay some of the *Handbook* text here briefly:

"Colin Horrabin, G3SBI, continued experimenting with variations of Jacob Mahkinson's original high-performance mixer circuit. This led to the development of a new mixer configuration called an H mode mixer. This name comes from the signal path through the circuit. See [*Handbook*] Fig 15.45A. Horrabin is a professional scientist/ engineer at the Science and Engineering Research Council's Darebury Laboratory, which has supported his investigative work on the H-mode switched-FET mixer, and consequently holds intellectual title to the new mixer. This does not prevent readers from taking the development further or using the information presented here."

"This is still the action of a switching mixer, but now the source terminal of each FET switch is grounded, so that the RF signal switched by the FET cannot modulate the gate volt-

age. In this configuration the transformers are important...."

See also *Experimental Methods in RF Design*, p 5.15. The four-FET mixer differed from earlier circuits since Ed Oxner, KB6QJ, of Siliconix in the 1970s used FETs as series switches, while Horrabin uses the FETs as grounded switches. This is still a commutating mixer, but transformer action now generates the needed signals, and it appears with one more transformer.

It has also been proved in passive diode-ring mixers[6] that a diplexer at the IF or the other ports is beneficial, because it provides the correct termination impedance over a broad frequency range. It has been employed

as well, at the IF port, in the CDG2000 project, a recent work by G3SBI and company. CDG2000 is an advanced transceiver project with a first mixer built around a Fairchild FST3125M IC[7] as an H-mode mixer.[8] This quad-FET bus switch IC is part of a family of bus switches now also manufactured by Philips as CBT3125, by TI as SN74CBT3125, by ON Semiconductor as 74FST3125, Pericom as PI5C3125 and perhaps others. The suffix may differ by package, but the small SOIC is better for this RF application.

The device has TTL/CMOS-compatible control inputs. The CDG2000 authors presented also a very low-noise LO synthesizer needed to reach high
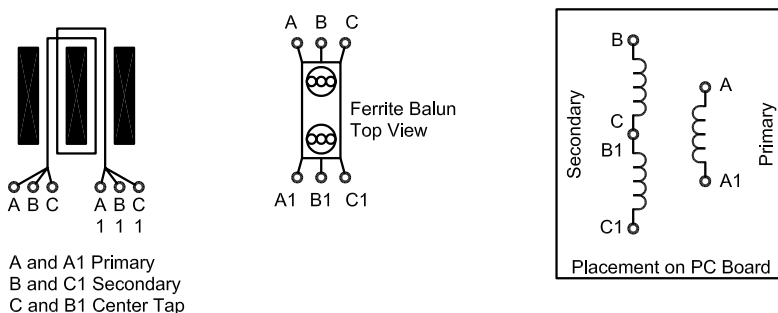
Fig 1—Ferrite binocular transformer winding details. First, label the ends of three pieces of #29 AWG enameled copper wire as shown, then twist them together. Wind four turns (see above, but four turns) of the twisted wire into an ferrite binocular-balun core (Amidon #BN-43-2402). On the finished transformer, ends A and A1 are the primary winding; ends B and C1 form the secondary, which has a center tap at B1 and C.
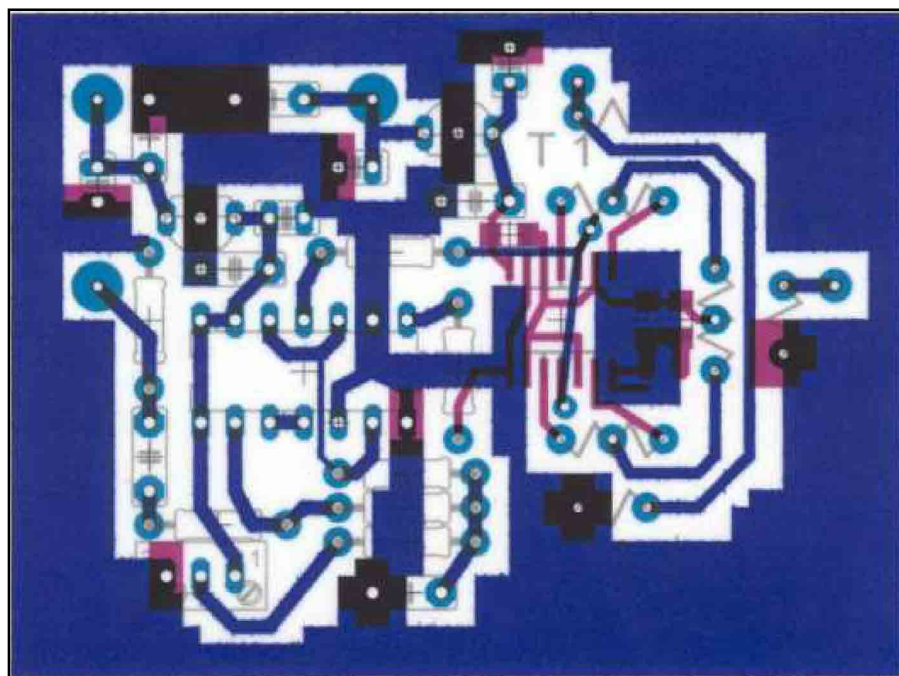
Fig 2—An enlarged x-ray view of the H-mode mixer board (no scale). Parts are shown in light gray.

dynamic range. I have fabricated a PC board around that basic version, with three transformers, but without a division by two of the LO frequency, just for simplicity and fundamental LO frequency availability. It is surely a fine way to get LO signals of the right phases and duty cycles for the "I" and "Q" outputs without any adjustment.

The original circuit was presented in *Radcom*, the RSGB monthly magazine, in Pat Walker, G3VA's column "Technical Topics" a few years ago by G3SBI.[9] I7SWX/F5VGU, Giancarlo Moda[10] is known to be the person who suggested to the triad of G3SBI, W7AAZ and W4ZCB to try an FST3125M IC for the H-mode mixer configuration to simplify the circuit with a lower cost IC, yet with reasonably good performance, with *IIP3* in the area of +40 dBm. (I remember some previously published schematics with an integrated quad D-MOSFET package with fast switching, see ARRL *Handbooks* of recent years.) Lately, Giancarlo published in *Radcom* a version with two transformers only, home-made around ferrite binocular beads, as a way to simplify tests for optimizing different frequency ranges. He used a process of rewinding them to find useful combinations of ferrite mix and number of turns, because he wanted to try this mixer for IFs as high as 70 MHz as a possible use in up-conversion commercial transceivers.

Giancarlo has already reported a positive experience in replacing the third mixer (a single-MOSFET type) with an early H-mode version with a 74HC4066 IC for 9 MHz to 455 kHz IFs, inside an old IC-751 transceiver. He wished to also replace the first mixer with a FST3125M, a faster and better-performance IC, time permitting.

Hannes Coetzee, ZS6BZP, previously mentioned a 74HC4066 IC as an analog-switch mixer in *RF Design* (June 1995, this is not an H-mode type). For four harmonically related bands (7 to 28 MHz), he achieved a direct-conversion to audio baseband receiver, with a fine audio chain, as seen in *Electronics World*, reprinted in *Communications Quarterly* (Oct 1998). Lately, I found on PA3CKR's Web site a brief evaluation report of the same early basic schematic, with three different types of transformer.[11]

As entertainment in his retirement,

I recently convinced my father Romano, I4FAF, a fast Amateur Radio homebuilder, to help me try both versions in practice. One with three transformers, and the I7SWX version, with two transformers.

I also discovered that JA9TTT, Mr Kato, had performed tests on both versions. He posted the spectrum-analyzer photos of his two-tone IMD tests on his personal Web site at **ja9ttt.homedns.org/**)

My father and I made a personal choice and selected the version with three transformers, mainly because we have previously employed home-
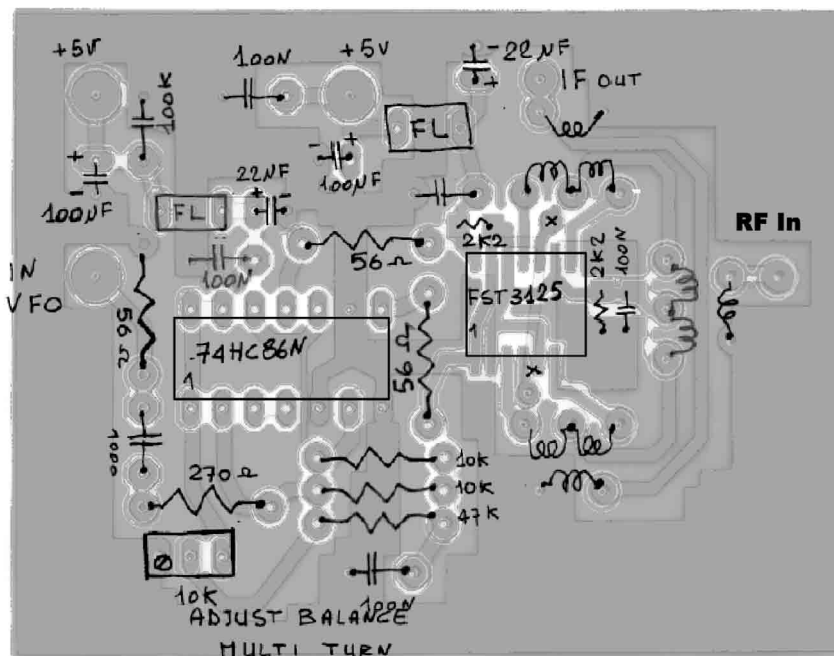

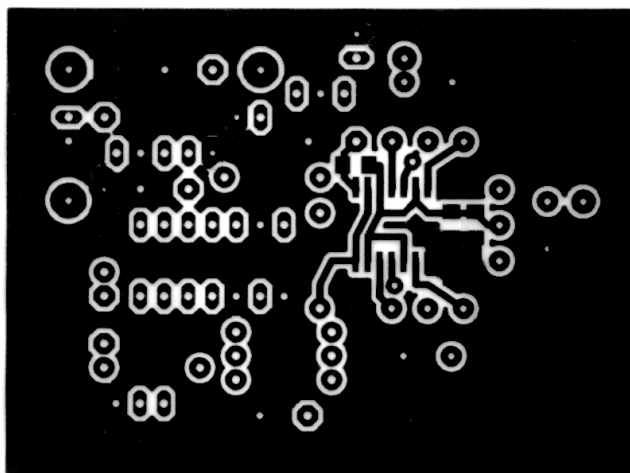**Fig 3—H-mode mixer PC board component values and placement (no scale).**

Fig 4—H-mode mixer PC board component-side etching pattern. The finished board should be 65×50 mm.
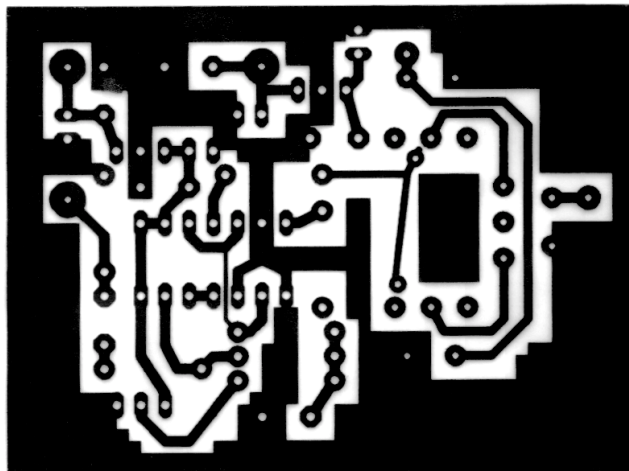

Fig 5—H-mode mixer PC board mirrored solder-side etching pattern. The finished board should be 65×50 mm.

made ferrite binocular-bead transformers and it seemed to us easier to wind them. (The version with two transformers has one with a five-filar winding.) Maybe the three transformers yield slightly better port isolation and higher *IIP3* values. Carefully review our performance data in Tables 1 through 4 below.

Some years ago in *QST*, we saw Ulrich Rohde's, KA2WEU, schematic[12] of a high-performance switch-mode mixer based on four D-MOS switching FETs as discrete components. Later, he showed us one circuit built around an SD5000 IC in *QEX* (Jan/Feb, 2003, pp 21-31).

Recently, ICOM announced, for their 40th anniversary of activity, a +40-dBm *IP3* transceiver. I must admit, however, that its price could be a valid cause for conjugal separation! Band conditions are variable; how well you do on the air depends also on the type of antenna you use and your location, so you don't always need such a bulletproof front end. Nonetheless, you can now enjoy an H-mode mixer with high *IP3* on a small budget. We are glad to share with you our experiences. We give you our PC board artwork and transformer details in Figs 1 through 5. We have had many requests, and readers showed much interest in it after my letter to the editor, published in *QEX*, Sept/Oct 2003.

Balance and Isolation Adjustment without a Spectrum Analyzer

Use one RF signal generator inside the 7 MHz band at –20 dBm level, 50 Ω output at the RF port. Use another RF generator at the LO port and connect your receiver with a 50 Ω coaxial cable to the mixer's IF port. An attenuator between mixer and receiver will mitigate mismatch effects caused by receivers that do not have perfect 50-Ω input impedances. Attenuation of 3-10 dB is enough; see *Handbook* tables for resistor values to build one. Tune the receiver to the 7 MHz signal and adjust the balance trimmer for minimum S-meter reading. This is a simple procedure for those without a spectrum analyzer, but our port-isolation data were all taken with an 80 dB-range spectrum analyzer.

Warning! Avoid leaving the input to the LO squarer open or with the input signal generator connected but switched off while dc is applied to the board. The squarer IC will show some signs of oscillation in such floating states and it gets warm. When a signal is applied to it, there is no problem. Giancarlo said he changed the squarer circuits to avoid self oscilla-

tions, but we did not experience that problem with the LO applied and running. Use a 74HC86 for maximum LO frequencies around 45-50 MHz; or better yet the 74AC86, which is about three times faster.

Performance Data

We performed a first test with the squarer logic signals inverted with respect to our schematic (see Fig 6), for balance evaluation with the slower HC logic squarer (see Table 1). We per-

Table 1
Test Data for H-MODE Mixer with FST3125M, Three-Transformer Version

Values shown for our evaluation PC board configuration, our transformers data, squarer 74HC86 pin 8 (complementary output) wired with 56 Ω resistor to pins 4 and 10 of FST3125M and pin 11 (Q output) wired with 56 Ω resistor to pin 1 and 13 of FST3125M). Decibel measurement accuracy around 1 dB.

RF (MHz)	LO (MHz)	IF (MHz)	RF-IF (dB)	LO-IF* (dB)	LO-RF* (dB)	Gain (dB)
28.5	37.5	9	38 (†21)	34 (†38)	27	–5.5
21	30	9	26 (†26)	33 (†32)	32	–5
14	23	9	37 (†26)	40 (†40)	34	–5
7	16	9	33	41	38	–5
3.7	12.7	9	36 (†36)	45 (†45)	41	–5
1.8	10.8	9	38 (†38)	46 (†46)	41	–5

Notes
RF in was 0 dBm, squarer used was 74HC86 (slower than 74AC86).
LO in was 0 dBm at squarer input.
*I cannot measure squarer output in dBm, so isolation is in decibels, LO to IF, is an attenuation seen on spectrum analyzer IF port of LO frequency referred to 0 dBm level (= RF in.) to give an idea of its level at IF port. We noticed a 10 dB improvement in LO-RF isolation if the two LO signals, Q and complementary, from the 74HC86 are routed in the opposite way to the FST3125M IC with a cross connection of both 56 Ω output resistors (as jumpers so pin 8 is routed to FST3125M pins 1 and 13 and pin 11 is routed to FST3125M pins 4-10 as shown in the main schematic).
RF to IF in dB, band optimized with adjust balance and
† measured values with adjust balance optimized for 7 MHz RF in. I think it is a good practical choice.

Table 2
Test Data for H-MODE Mixer with FST3125M, Three-Transformer Version

Values shown for our *SMD PC board* configuration, our transformer data, with *SMD* squarer *74AC86* pin 8 (complementary output) wired through 56 Ω resistor to pins 4 and 10 of FST3125M and pin 11 (Q output) wired through a 56 Ω resistor to pins 1 and 13 of FST3125M. Decibel measurement accuracy around 1 dB.

RF (MHz)	LO (MHz)	IF (MHz)	RF-IF (dB)	LO-IF* (dB)	LO-RF* (dB)	Gain (dB)
28.5	37.5	9	44 (†36)	37 (†37)	38	–5.5
21	30	9	39 (†39)	48 (†47)	39	–5
14	23	9	49 (†47)	43 (†43)	44	–5
7	16	9	48	47	45	–5
3.7	12.7	9	66 (†47)	45 (†45)	46	–5
1.8	10.8	9	66 (†37)	46 (†46)	48	–5

Notes
Balance seams slightly better with the SMD PC board, so is average port isolation.
RF in was 0 dBm, squarer used was 74AC86 in a small SOIC package (about three times faster). LO in was 0 dBm at squarer input
* I cannot measure squarer output in dBm, so isolation in dB, LO to IF, is an attenuation seen on spectrum analyzer IF port of LO frequency referred to 0 dBm level (= RF in) to give an idea of its level at IF port. RF to IF in decibels, band optimized with adjust balance and
† measured values with adjust balance optimized for 7 MHz RF in. I think it is a good practical choice.

formed a second test with squarer logic signals inverted with respect to our schematic for balance evaluation with the faster AC' small SOIC squarer (see Table 2). Finally, we performed a third test (with logic signals as shown in the main schematic) for balance evaluation and with the faster AC small SOIC squarer. That proved to be the better combination (see Table 3). Two-tone third-order IMD data for our H-mode Mixer with the FST3125 and three transformers are found in Table 4.

Figs 7 and 8 show data taken by JA9TTT, Mr. Kato, that are available on his Web site[13] as photos from an Advantest TR4171 Spectrum Analyzer with his two-tone test setup. We have carefully—and with a lot of patience—calculated the corresponding *IIP3* values from the data. My Spectrum Analyzer system with around 80 dB of SFDR is not enough for the >90 dB of SFDR.

Tests of the two-transformer version have been performed around three homemade Amidon binocular-bead transformers of the same size but of different permeabilities. See Table 5 for BN43-2402; Table 6 for BN61-2402 and Table 7 for BN73-2402.[14] It is important to read the note pertaining to these tables. It is clear that BN43-2402 is the winner here and we were very pleased to agree with those data, since we already se-lected BN43-2402 in our personal tests. We informed I7SWX about these JA9TTT data because he had the same problem, no such high SFDR instruments test-set available in his early development of the two-transformer H-mode mixer version. Someone guessed that a mixer with only two transformers could contribute less to IMD than one with three; but by these data, it is not proved. The three-transformer version is still slightly better.

Table 3
Test Data for H-MODE Mixer with FST3125M, Three-Transformer Version

Values shown for our SMD PC board configuration, our transformers data, with SMD squarer 74AC86 pin 8 (complementary output) wired through a 56 Ω resistor to pins 1 and 13 of FST3125M and pin 11 (Q output) wired through a 56 Ω resistor to pins 4 and 10 of FST3125M. Decibel measurement accuracy around 1 dB.

| RF (MHz)	LO (MHz)	IF (MHz)	RF-IF (dB)	LO-IF* (dB)	LO-RF* (dB)	Gain (dB)
28.5	37.5	9	64 (†38)	48 (†48)	44 (†45)	−5
21	30	9	80 (†49)	42 (†42)	52 (†54)	−5
14	23	9	60 (†50)	44 (†45)	52 (†55)	−5
7	16	9	70	50	58 (†58)	−5
3.7	12.7	9	66 (†38)	53 (†53)	62 (†62)	−5
1.8	10.8	9	72 (†38)	55 (†54)	64 (†63)	−5

Notes
Balance is better with the SMD PC board and fast AC squarer and so is average port isolation.
RF in was 0 dBm, squarer used was 74AC86 small SOIC package (about 3 times faster).
LO in was 0 dBm at squarer input .
I cannot measure squarer output in dBm, so isolation in dB, LO to IF, is an attenuation seen on spectrum analyser IF port of LO frequency referred to 0 dBm level (= RF in.) to give an idea of its level at IF port. RF to IF in dB, band optimized with adjust balance and
†measured values with adjust balance optimized for 7 MHz RF in. I think it is a good practical choice.
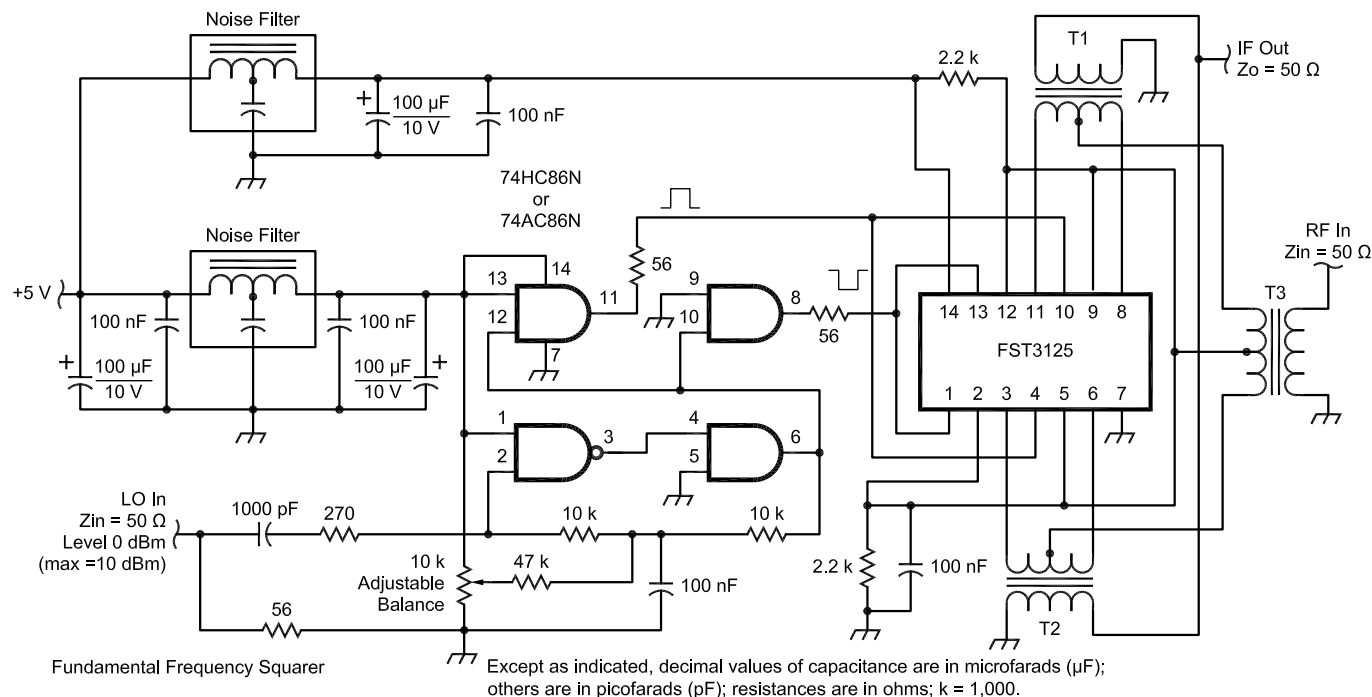
Fig 6—Schematic of the IK4AUY-I4FAF three-transformer H-mode mixer.

Table 4
Two-tone Third Order IMD Tests: Figure of Merit *IIP3*

H-mode mixer with FST3125 IC and three transformers.

Author	Frequency (MHz)	IMD (dB)	OIP3 (dBm)	IIP3 (dBm)	G (dB)
CDG2000 by	RF in 30, LO 39, IF 9			37 @ 14	−4 @ 30
G3SBI & Co*	RF in 2, LO 11, IF 9			40 @ 3.5	−5.5 @ 2
PA3CKR**†	he tested three types of transform see his Web site for details.			+41 to 44	−6
JA9TTT†	RF in 7.43, 7.44, 2x0 dBm IF 17 MHz (LO 10 MHz)	94 dB down	+41	+47	−5.9
JA9TTT†	RF in 7.43, 7.44, 2x0 dBm IF 9 MHz	85 dB down	+36.6	+42.5	−5.9
JA9TTT†	RF in same as above IF 2 MHz	63 dB down worst 30 dB	+24.5	+31.5	−7
JA9TTT†	RF in as above IF 455 kHz	40 dB down (ferrite limit)	+8.5	+20	−11.5
JA9TTT†	as above IF 27 MHz	85 dB down	+36.7	+42.5	−5.8

Notes
*FST3125 power supply at 7 V. The LO runs at twice the required frequency and is divided by two with a 74AC74. I suggest you read the series in *Radcom* (RSGB) from June to December, 2002. It describes a very good receiver design and low-noise synthesizer. Performance numbers are on page 19, July, 2002, with complaints for a (relatively) slightly lower *IIP3* due to transformers. G3OGQ told me he and G3SBI tested 15 different types of transformers and the best results where with Mini Circuits TT4-1A, yielding about 5 dB better *IP3* than hand wired transformers (BN202-43). Also see *Experimental Methods in RF Design* (Newington, Connecticut: ARRL, 2003) for a logic circuit for blanking.
PA3CKR Web site **www.qsl.net/pa3ckr/
†JA9TTT Web site and IK4AUY-I4FAF **www.qsl.net/ik4auy/** evaluating board are of the same basic configuration, with a fundamental-frequency squarer and a 74HC86, usable with LOs up to 45/50 MHz or better (almost three times faster) 74AC86 SOIC.

More Experiments with FST3125M: A Sample-and-Hold-Type SSB-CW Detector

By now, we are already receiving very well on the 20-m band. With a laboratory signal generator LO, we also got good readability and clean reception of 3CØV (Annóbon Island) on 7.049 MHz with a dipole antenna. Now, our prototype receiver system is as follows:

- An analog, air-variable capacitor 5 MHz VFO;
- A 9-MHz IF with diplexer and INRAD SSB-CW quartz band-pass filters;
- A Bill Carver, W7AAZ-designed 120-dB-range AGC/IF amplifier unit;[15]
- Followed by an experimental sample-and-hold switch-mode SSB-CW product detector, taking signals from 9 MHz to audio.

We used an FST3126M fast switch with a lower on resistance. The typical value is 4 Ω. We compared this sample-and-hold detector with one built around a 74HC4066 in a circuit originally presented by Rohde for a lower IF of 1.44 MHz.[16] The 74HC4066 is a pin-for-pin replacement for the CD4066, but it requires PC board modifications, since the '4066 is not a pin-for-pin replace-
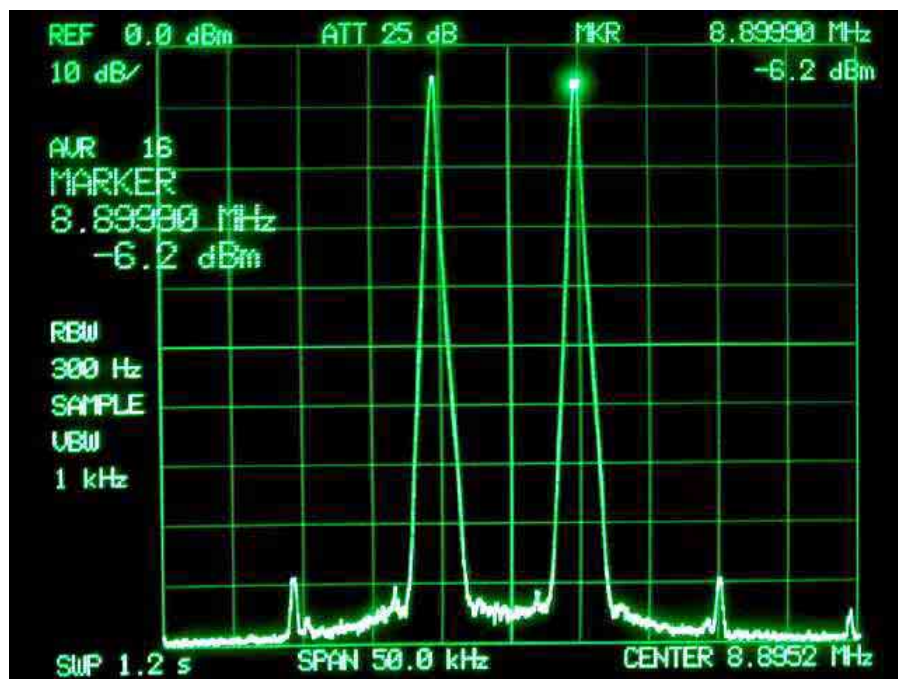

Fig 7—Two-tone IMD of an H-mode mixer with mix 43 transformers using two transformers (I7SWX type) at 9 MHz. (Takahiro Kato, JA9TTT, 2T_43_9M.jpeg at ja9ttt.homedns.org/hamf/myexp/2T-H-mode-DBM.html)

ment for the FST3125M (the switching logic is also different).

The original sample-and-hold schematic adapted for an FST3126M is fine.

We got clear, crisp audio. This IC is equivalent to FST3125M and it has direct switching logic as in the CD4066 or 74HC4066, so a logical 1 connects

Table 5—Two Transformer Version

Design based on G. Moda, I7SWX, article in *Radcom* (RSGB, TechTopics, April 2003, pp 82-83). Data tested by JA9TTT, Mr. Kato, from his Web site: two-tone third-order IMD, *IIP3* and Gain. Some data not given there were carefully calculated by the author from Kato's original Spectrum Analyzer photos (Advantest TR4171 with at least 90 dB SFDR two-tone and spectrum analyzer system). Both transformers wound on Amidon BN43-2402 binocular cores. (See Note 14.)

Author	Frequency (MHz)	IMD (dB)	OIP3 (dBm)	IIP3 (dBm)	G (dB)
JA9TTT	RF in 7.43, 7.44, 2x0 dBm IF 17 MHz (LO 10 MHz)	88 dB down	+38.7	+44	−5.3
JA9TTT	RF in 7.43, 7.44, 2x0 dBm) IF 9 MHz (LO 16.4)	82 dB down	+35	+41.2	−6.2
JA9TTT	RF in same as above IF 2 MHz worst	63 dB down 30 dB	+24.5	+31.5	−7
JA9TTT	RF in as above IF 455 kHz	41 dB down (ferrite limit)	+14	+20.9	−6.9
JA9TTT	as above IF 27 MHz	78 dB down	+34	+39	−5.3

Port-isolation data (JA9TTT): RF to IF around 27 dB (with RF in at 0 dBm), LO to IF around 50 dB (LO = 10 MHz).

Table 6—Two Transformer Version

Data test by JA9TTT, Mr. Kato, from his Web site: two-tone third-order IMD, *IIP3* and Gain. Some data not given there were carefully calculated by myself from Kato's original Spectrum Analyzer photos (Advantest TR4171 as above). Both transformers on Amidon BN61-2402. (See Note 14.)

Author	Frequency (MHz)	IMD (dB)	OIP3 (dBm)	IIP3 (dBm)	G (dB)
JA9TTT	RF in 7.43, 7.44, 2x0dBm IF 17 MHz (LO 10 MHz)	75.8 dB down	+33	+37.9	−4.9
JA9TTT	RF in 7.43, 7.44, 2x0dBm IF 9 MHz (LO 16.4)	75 dB down	+32	+37.5	−5.5
JA9TTT	RF in same as above IF 2 MHz	76.8 dB down	+33	+38.4	−5.4
JA9TTT	RF in as above IF 455 kHz	47.8 dB down (ferrite limit)	+18	+23.9	−5.9
JA9TTT	as above IF 27 MHz	64.2 dB down	+27	+32.1	−5.1

Port-isolation data (JA9TTT): RF to IF around 23 dB (with RF in at 0 dBm), LO to IF around 48 dB (LO = 10 MHz).

Table 7—Two Transformer Version

Data test by JA9TTT, Mr. Kato, from his Web site: two-tone third-order IMD, *IIP3* and Gain. Some data not given there were carefully calculated by the author from Kato's original Spectrum Analyzer photos (Advantest TR4171 as above). Both transformers on Amidon BN73-2402. (See Note 14.)

Author	Frequency (MHz)	IMD (dB)	OIP3 (dBm)	IIP3 (dBm)	G (dB)
JA9TTT	RF in 7.43, 7.44, 2x0 dBm IF 17 MHz (LO 10 MHz)	47 dB down	+17	+23.5	−6.5
JA9TTT	RF in 7.43, 7.44, 2x0dBm IF 9 MHz (LO 16.4)	47.2 dB down	+18	+23.6	−5.6
JA9TTT	RF in same as above IF 2 MHz	48.6 dB down	+19	+24.3	−5.3
JA9TTT	RF in as above IF 455 kHz	48.6 dB down	+19	+24.3	−5.3
JA9TTT	as above IF 27 MHz	45.8 dB down	+16	+22.9	−6.9

Port-isolation data (by JA9TTT): RF to IF around 29 dB (with RF in at 0 dBm), LO to IF around 47 dB (LO = 10 MHz)

Table 8
Expected Accessory and Modification Impacts on a Receiver

Device	IP2	IIP3	MDS	SFDR	XM	lo PNDR	comments
Passive Passband Filter between Antenna/Receiver	++	++(=IL)	–(Inserton Loss)	=/depnds Δf two tones	+	=	desirable ††
Atten. On	+	++(=atten.)	— (=atten.)	=	++	=	††
Preamp On	–	—	+, depends	-, depends	–	=	in some cases
Preamp Off	+	++	—	=	++	=	††
Internal Mods in "Black Boxes"	+	++ ie mixer mod	+	++ ie mixer mod	+	+	>more difficult

Notes

+ expected improvement , - expected worsening, = no or minimal variation.

††With an RF attenuator on you shift the receiver dynamic range starting point upward. There's a similar effect with the preamplifier turned off (called also IPO). This is a step to try. With preamp on, you shift receiver dynamic range starting point downward. Use carefully, in some band/antenna-system circumstances it is probable that SFDR could be even deteriorated if preamp is limited in *IIP3, NF*, in presence of strong in-band signals. See also D. Smith, KF6DX, "More On Receiver Dynamic Range" in **www.doug-smith.net/moredynamics.htm**.

port A to port B (see Note 7). We also modified the audio output stage because we found that in our implementation, the original low-pass filter circuit showed more gain than needed in our application. It was originally built around a TL074, a quad amplifier IC that proved much too noisy. So, we replaced that audio portion with a dual-stage, dual-supply circuit that uses a Motorola MC33078P IC as audio buffer and low-pass filter, with a low amount of voltage gain (around 5), directly driving a trusted TDA2003 IC audio power amplifier for 4-8 Ω headphones or speakers. We used the same 74AC86 squarer for I and Q signals at the LO/BFO.

With a spectrum analyzer or receiver at the IF port, we could adjust the balance trimmer for a minimum value of the closer even LO/BFO harmonics. The BFO-IF isolation was a nice 36 dB, or about 10 dB of improvement over a 74HC4066 version; but the '4066 seemed less critical in its original circuit. This type of switching product detector showed an audio output level of around one-third the input level. So for a 1100 mV(P-P) 9-MHz IF signal in, output was around 450 mV(P-P) with no visible distortion on the sinusoids. Together with our audio buffer and LPF, the output level is 6 dB down at 4 kHz—fine for broad-range SSB audio. Of course, the beginning of our receiver chain is our front-end unit, as presented in Mar/Apr 2003 *QEX* (pp 45-56).

We wanted to test this prototype receiver during the 2003 CQWW DX SSB contest. That's why IR4B, my contest call, showed up as only a part-time entry into this year's competition.

Table 9
Component List

ICs

FST3125 M (Fairchild), 14 lead SOIC small package
74HC86 or 74AC86, 14 lead plastic dual in line package

Resistors (normal carbon film $^1/_4$ W, 5%)

56 Ω, 2
270 Ω, 1
2200 Ω, small chip, 2
10 kΩ, 2
47 kΩ, 1
10 kΩ, multiturn trimpot PC board variable resistor, vertical

Capacitors

1000 pF, small ceramic, 1
100 *NF*, small chip, 1 (it is the one in parallel with a 2200 Ω chip resistor)
100 *NF*, small ceramic multilayer for ac decoupling, 4
100 µF, 25 V electrolytic, 3

Noise filter, small integrated LCL, three-lead package, 2
T1,T2,T3—BN-43-2402 (OD 0.280, height 0.240 inches) Amidon, 3. See ferrite Binoculars winding details in Fig 4.

Comparing the prototype with two other receivers—a fully analog receiver and a Kenwood TS570DG—We were pleased with the on-air experience on 10-160 m with a lot of strong signals around. Audio quality was very good and pleasing to the ear.

We tested it with a Marconi signal generator for noise floor at around –127 dBm in a 2.4 kHz bandwidth with no preamplifier/BPF ahead of the first H-mode mixer (–5 dB loss). Because it was not assembled yet, there was no further amplification after the 9 MHz IF SSB-CW crystal filters (–3.5 dB loss for SSB filter and –7 dB

for CW) before the W7AAZ IF-AGC amplifier unit was used. The IF amplifier is capable of a lot of gain. Its noise floor is 0.03 µV = –137 dBm and it has an AGC range of 120 dB, starting at –128 dBm, so it must be very well shielded. By comparison, the CDG2000 has one post amplifier to compensate for roofing-filter losses.

Be careful about the BFO because in this single-IF-conversion architecture, its frequency is effectively very close to the IF. The BFO must be well shielded in a separate metal box. Reduce its level inside the box to the 0 dBm needed for the product detec-

tor and use double-shielded or 100%-shielded 50-Ω coax cable for RF connections. We usually prefer more gain distribution, and we also got good results with an all-MOSFET IF AGC/amplifier unit with W7ZOI's filter tailending technique; but we find quite attractive—and much more flexible—a receiver architecture with a good mix of high-quality analog and digital/DSP circuits. We're pleased with the result.

For weak-signal performance, you still need a quiet IF-gain distribution, a well-behaved AGC with the proper threshold and time-constant selection under different conditions[17] and proper phase delay in the sharp bandpass filters. A high-quality product detector and noiseless audio stages alleviate listening fatigue. All those critical issues work together with an LO having the lowest possible phase noise.

Epilogue

We have observed consistent results in three units built, but the transformers must be identical. Here's an odd thing: If the I and Q LO signals from the 74HC86 are routed in opposite directions to the FST3125M with cross-connection of both 56 Ω output resistors (as jumpers, so pin 8 is routed to FST3125M pins 1 and 13, and pin 11 is routed to FST3125M pins 4 and 10), you achieve even better LO-RF isolation—by about 10 dB.

Design bonuses include that only a 5 V dc low-current supply is required, fundamental LO frequency input is around 0 dBm and you get very high *IIP3* with acceptable port isolation and reasonable parts expense.

The practical goal of this article are to share with you my own experiences and those of other authors with H-

mode mixers built around a bus-switch IC, to provide an evaluation PC board and some data. The original three-transformer version yielded slightly better *IIP3* results and port isolation than the two-transformer version. Port isolation is frequency-dependent with balance adjustment. We obtained better than average isolation values with a smaller, all-SMD PC board together with ac logic. Please visit my Web site at **www.qsl.net/ik4auy/**.

The two-transformer version is close in performance and could be used for replacement in some older commer-

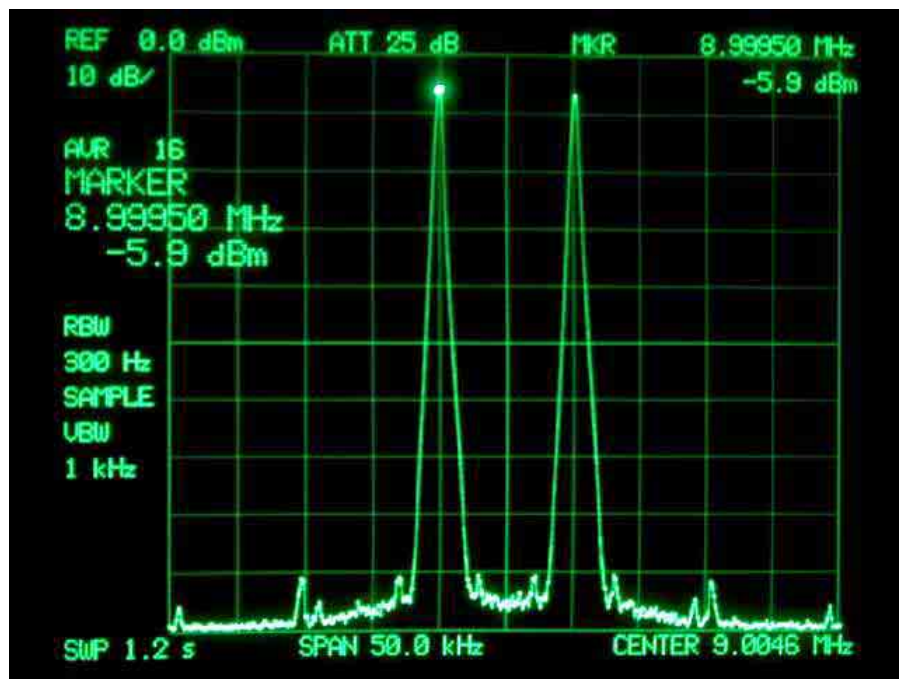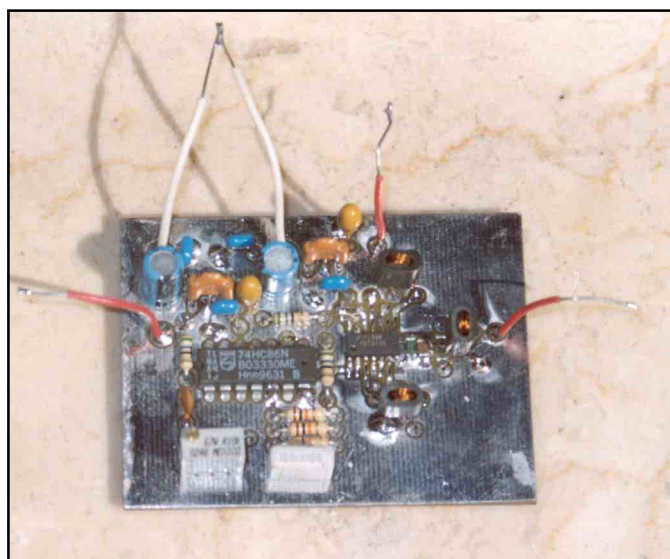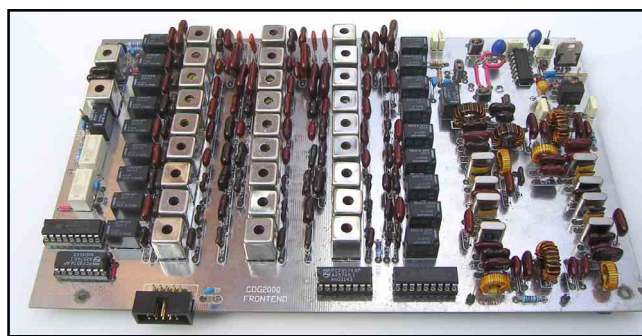cial radios if a smaller PC board were designed where space is at a premium.

Fig 8—Two-tone IMD of an H-mode mixer with mix-43 transformers using three transformers (G3SBI/W7AAZ type) at 9 MHz. (Takahiro Kato, JA9TTT, (H_DBM_9_0.jpeg) at ja9ttt.homedns.org/hamf/myexp/H-mode-Mixer.html)

(A)

(B)

Fig 9—(A) The IK4AUY and I4FAF mixer evaluation board. (B) The CDG2000 front-end board incorporating the mixer. The mixer's three transformers are visible at the upper-right corner. The front end has relay switching for T/R and attenuators, a 9 MHz notch filter, 9 HF passband filters (Butterworth shape) with dc "wetted" relay contacts, H-mode mixer here built by us with our homebrew three binocular transformers, a 74AC74 LO divide-by-two squarer, diplexer and special double roofing filter with input and output hybrid couplers with SSB bandwidth, a computer control interface.

their terrific work in developing an advanced Amateur Radio project, the CDG2000; and to G3XJP for a fine "PIC a Star: a software transmitter and receiver." Also, many thanks to my father Romano, I4FAF, patient builder of our evaluation board (Fig 9A) and front-end board for the CDG2000 (Fig 9B).

Notes

[1]S. Cartoceti, IK4AUY, "A High-Level Accessory Front-End for the HF Amateur Bands," *QEX*, March/April 2003, pp 45-56. Feedback in "Letters to the Editor" for one errata and performance data in *QEX*, May/June 2003, p 63.

[2]U. Rohde, KA2WEU/DJ2LR, "Key Components of Modern Receiver Design: A Second Look," *QST*, Dec 1994, pp 38-44. Also Part 1 in *QST*, May 2003, pp 29-32; Part 2, June 1994, pp 27-31.

[3]U. Rohde, KA2WEU, "Theory of Intermodulation and Reciprocal Mixing," Part 2, *QEX*, Jan/Feb 2003, pp 21-31. A good look at measuring *IP3* in mixers, and there is a schematic of an high performance switching type mixer around SD5000 IC reporting *IP3* in the range of 36 to 42 dBm. U. Rohde, DJ2LR, "Communications receivers for the year 2000," *Ham Radio* (now on CD ROM from ARRL), Nov 1981, pp 12-29. Page 5 presented a two-FET passive high-level mixer. Doug DeMaw, W1FB (SK), and AD0W, "Modern Receiver Mixers for High Dynamic Range," *QST* Jan 1981, pp 19-23. For a nice look at the performance of some more traditional active and passive diode mixers, also see "*IP3* Discussion" by John Torpe of AOR UK (LTD) **www.aoruk.com/comments.htm**.

[4]W. Hayward, W7ZOI; R. Cambell, KK7B; and R. Larkin, W7PUA, *Experimental Methods in RF Design* (Newington: Connecticut: ARRL 2003), pp 5.15, 6.9-6.11, 6.27-6.53. L. Asbrink, SM5BSZ, "*Linrad*: New Possibilities for the Communications Experimenters," Part 4, *QEX* Sept/Oct 2003, pp 29-31.

[5]Agilent Web site for *APPCAD* software, V 2.51, **ftp.agilent.com/pub/semiconductor/morpheus/docs/setup251.exe** or for version 3.02 in **www.hp.woodshot.com/**.

[6]J. Stephensen, "Reducing IMD in High-Level Mixers," *QEX*, May/June 2001, pp 45-50. It's also in *Experimental Methods in RF Design* companion CD.

[7]FST3125M Fairchild data sheet at **www.fairchildsemi.com/pf/FS/FST3125.html** (with logic 0=port A connected to B, logic 1=open or high impedence). FST3126M data sheet at **www.fairchildsemi.com/pf/FS/FST3126.html** is pin-to-pin compatible with FST3125M, but switching logic is logic 0=port A is open or high impedance to port B, logic 1=port A connected to B, this is same logic as CD4066 or 74HC4066.

[8]CDG2000 by G3SBI, G3OGQ, G8KBB in *Radcom* (RSGB) June-Dec 2002 and also in Warrington Amateur Radio Club Web site at **www.warc.org.uk/**.

[9]The first announcement about an H-mode mixer seems to be in *Radcom,* Technical Topics (TT), Oct 1993, pp 55-56 by Colin Horrabin, G3SBI and in TT of July, Aug, Sept 1998. Also *Radio Communication Handbook*, RSGB, sixth ed., pp 6.48-6.53.

[10]Giancarlo Moda, I7SWX/F5VGU, "I7SWX Two-Transformer H-mode Mixer," *Radcom* magazine (RSGB), in TT, April 2003, pp 82-83; "Modifiche al ricevitore dell'IC 751 per migliorarne l' *IP3*. "An H-mode mixer application, In *Radio Rivista,* ARI magazine, April 2002, p 21; "Nuovi Mixer ad elevata dinamica," *Radio Rivista*, March 1999, p 29; "Il Mixer digitale," *Radio Rivista*, July 1997, p 28; I7SWX's switched-ring mixer with FST3125 in *Radcom*, TT, Sept 2003, pp 70-71. For a late application following I7SWX's earlier experiences in a complete front-end and transceiver project, see Peter Rhodes, G3XJP, "Pic a Star: a software Transmitter and Receiver," *Radcom*, Nov 2003, pp 84-85.

[11]PA3CKR Web site **www.qsl.net/pa3ckr/hlmixer/index.html**.

[12]U. Rohde, KA2WEU/DJ2LR, "Recent Advances in Shortwave Receiver Design," *QST*, Nov 1992, p 51.

[13]**ja9ttt.homedns.org/hamf/myexp/H-mode-Mixer.html**.

[14]Notes for Tables 5, 6 and 7: Test data by JA9TTT about I7SWX two-transformer version but with the squarer circuit (74HC86 or 74AC86) used in our three-transformer version. One transformer is a four pentafilar (4×5) winding, wire diameter is 0.16 mm (#34 AWG). Be careful to correctly wind ferrite binoculars. Giancarlo Moda has detailed his experience with the FST3125M H-mode mixer in his article (April, 2003, *Radcom*), but he could not give performance data due to lack of suitable laboratory grade instrumentation (to measure such high *IIP3* or low third-order IMD levels). He presented a no-adjustment fundamental-frequency squarer. Avoid leaving the LO input to the squarer open or with a signal generator connected but off, with dc applied to the board. This can generate random frequencies, and the circuit can get warm. When a signal is applied to it, there is no problem. Giancarlo said he changed the squarer circuit to avoid self oscillation, but we didn't experience that problem with an LO signal applied to it (use 74HC86 for maximum LO, around 45/50 MHz—or better a 74AC86 IC about three times faster).

[15]W. Carver, K6OLG (now W7AAZ), "A High-Performance AGC/IF Subsystem," *QST*, May 1996, pp 39-44 (also in *Experimental Methods in RF Design,* ARRL book companion CD).

[16]U. Rohde, KA2WEU, "Recent Advances in Shortwave Receiver Design," *QST*, Nov 1992 p 53.

[17]D. Smith, KF6DX, "Digital Automatic Gain Control for Radio Transceivers" in **www.doug-smith.net/digitalagc.htm**. Look also at the very fine L. Asbrink, SM5BSZ, technical site **antennspecialisten.se/~sm5bsz/index.htm** for weak-signal reception and receiver tests. For a nice 110 dB dynamic range from 0.05 to 60 MHz Vector Network Analyzer with passband gain and group delay display by N2PK: **users.adelphia.net/~n2pk/index.html**.

***IK4AUY, Sergio**: Amateur Radio license at 16, active since 1980 as his father I4FAF's second operator. He got his own call at 18. He is now 39, and still enjo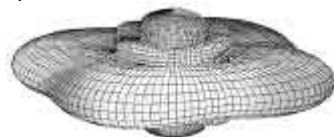ys DX and Contests. Sergio holds a degree in economics and commerce from Bologna University and works in a local bank as credit analyst. He started young and read a lot of good amateur related books and magazines in his spare time.*

He holds S79AU from the Seychelles Islands and Amateur Extra US license AC7PC (my Italian address only is good for mail), 5BDXCC Challenge and is on the DXCC Honor Roll as well. In some contests he uses special call IR4B, and he is one of Marconi Memorial Station (IY4FGM) official operators from his summer home where he started, young, his first wireless radio experiments, now mausoleum and museum, in Pontecchio Marconi (Bologna). Sergio and other IY4FGM operators work in the organizational team of the annual Italian HF DX Convention at the end of September.

***I4FAF, Romano,** is an old timer in Amateur Radio; his age is 70. He started young at 18 by repairing radios in the Navy. He has been an ARRL member since 1980. He is on the DXCC Honor Roll. I4FAF mainly enjoys homebrewing since retirement, having built HF transceivers, power amplifiers and test equipment.*

Both Romano and Sergio are members of ARI, the Italian national association, and the ARRL. They have published five technical articles in Radio Rivista *since 2000. They have a Web site at **www.qsl.net/ik4auy/**.* □□