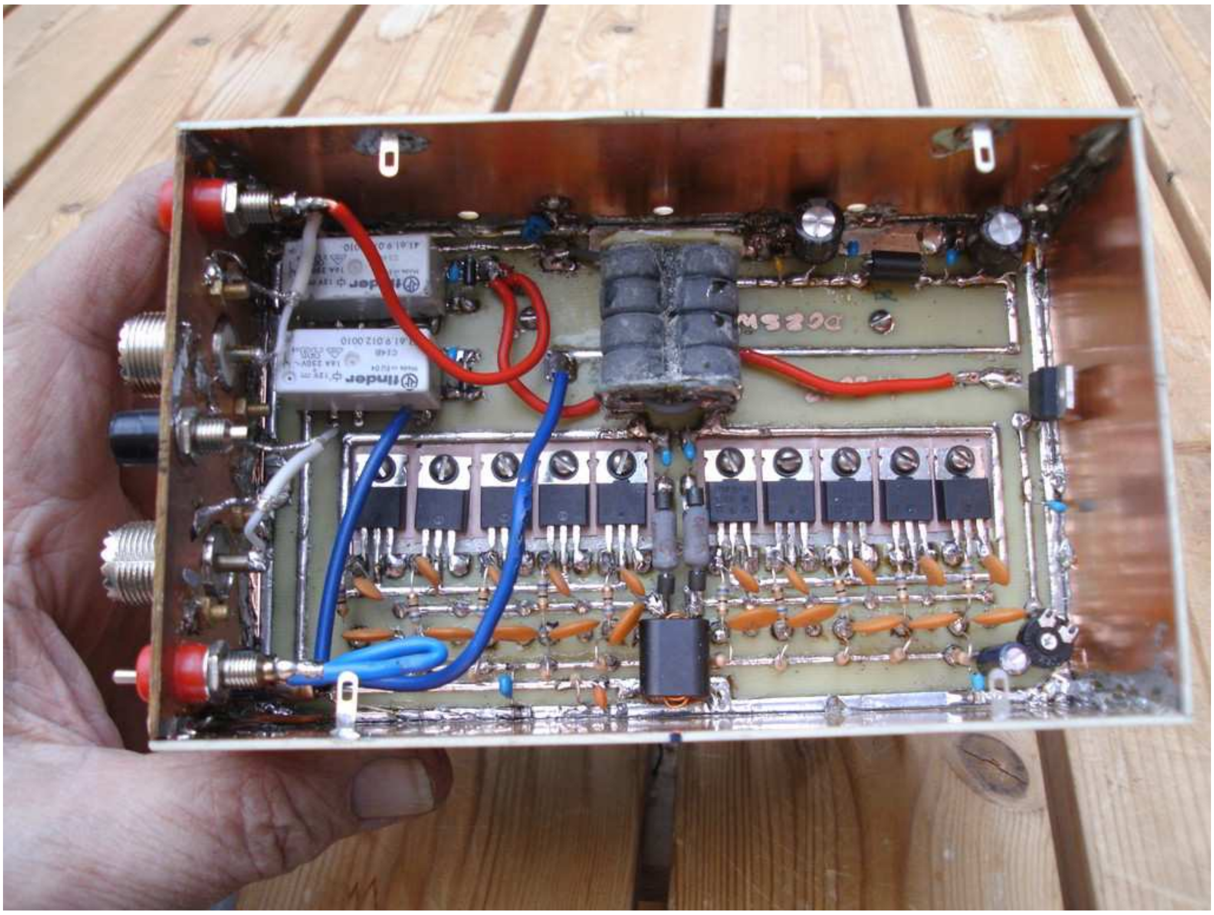
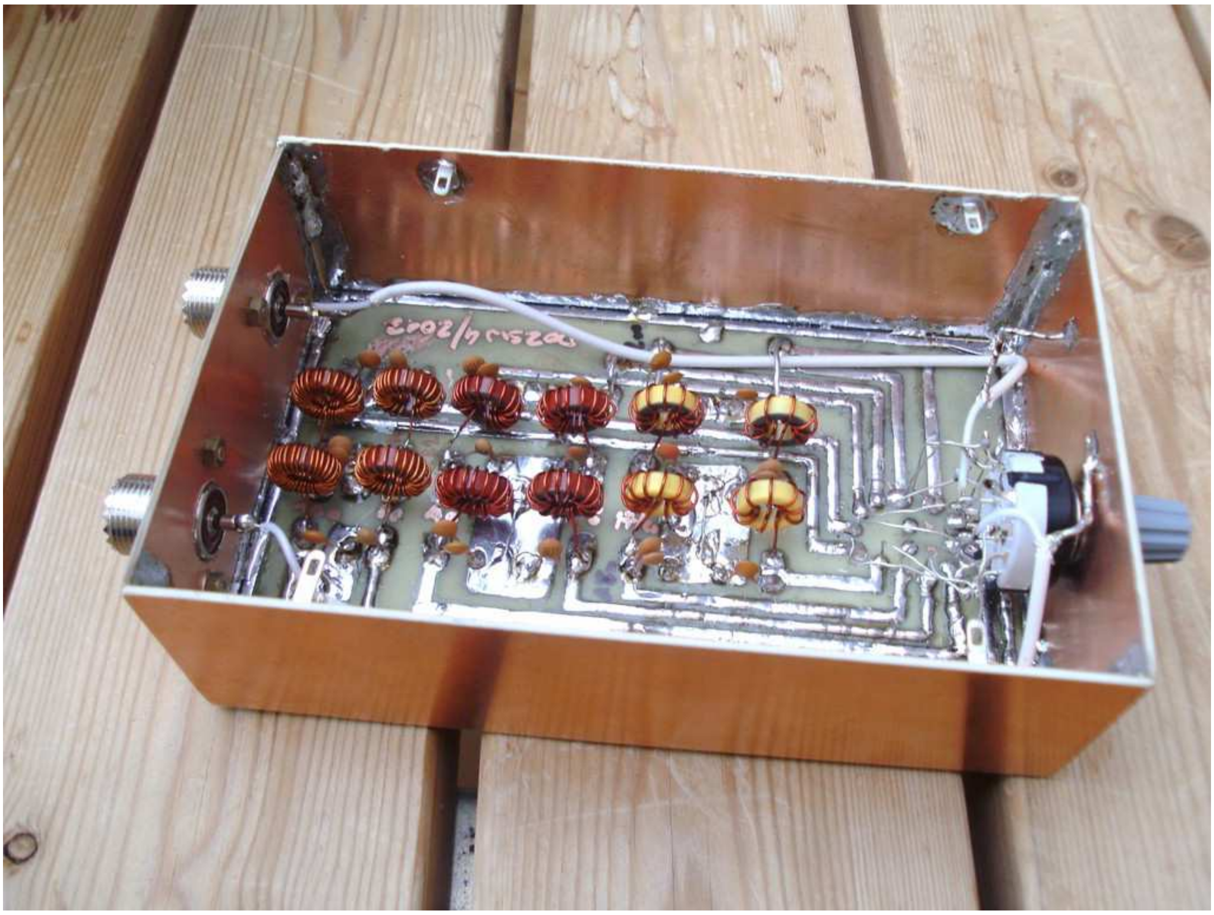
Eine 100 Watt Endstufe,
kostengünstig und einfach zu bauen.

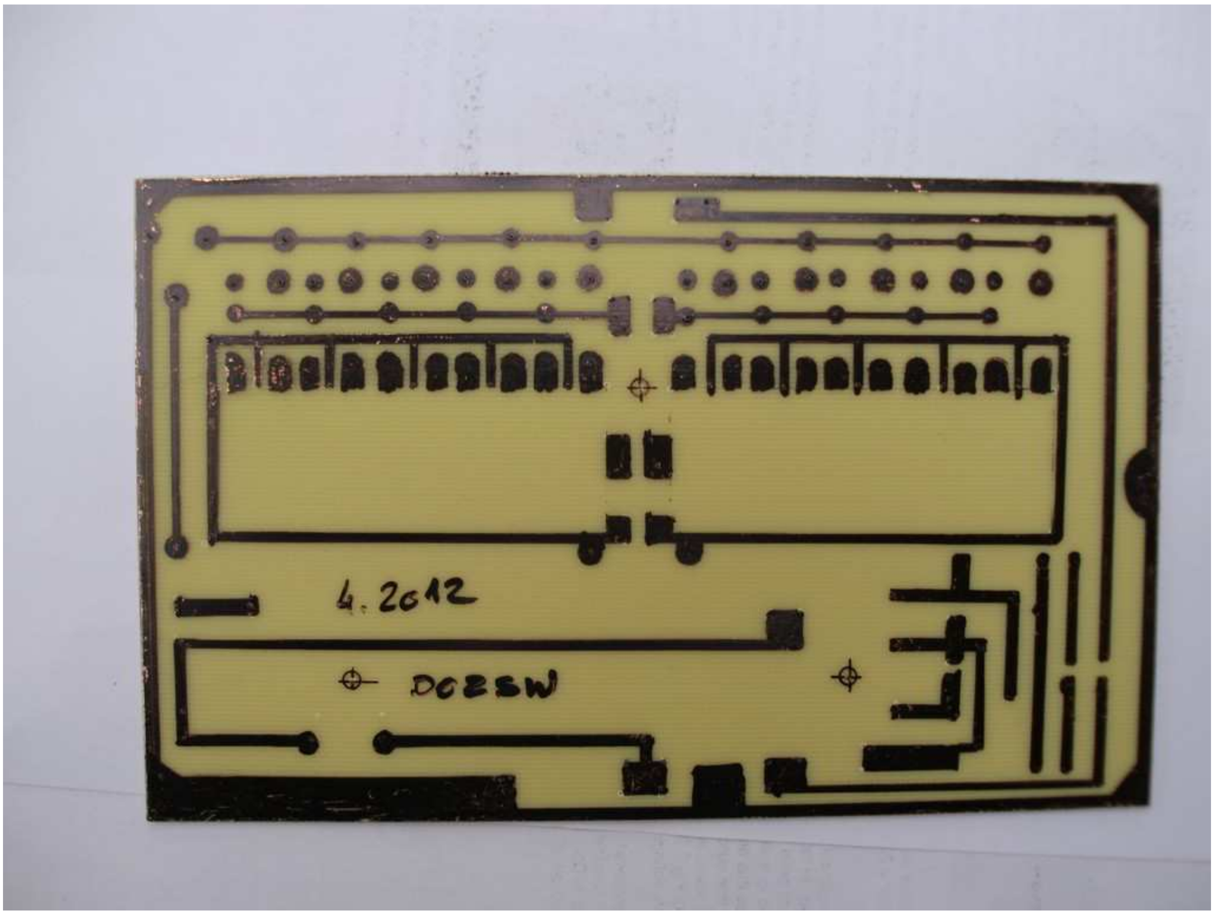
Fertige Endstufe:



Filterbaugruppe



Platine unbestückt



Platine herstellen - Bestückung und Abgleich

**Die Platine ist als Lötinseltechnik ausgeführt.
Alle Bauteile werden stumpf aufgelötet. Es wird eine
doppelt kaschierte Platine im Europakartenformat
10 x 16 cm benötigt.
Die Lötpunkte des Layout`s werden mittels eines Stahlstiftes
auf der Platine markiert ,und mit einem Permanent-Edding ausgefüllt.
Dann werden die Lötpunkte gemäß Layout verbunden.
Die Rückseite wird mit Klebefolie abgeklebt und das Ganze geäzt.
Die Ausschnitte zur Aufnahme der IRF 510 sind herzustellen, sowie die
Durchkontaktierung zur Masseseite(Rückseite).
Die Bestückung erfolg gemäß Schaltbild und Bestückungsplan.**

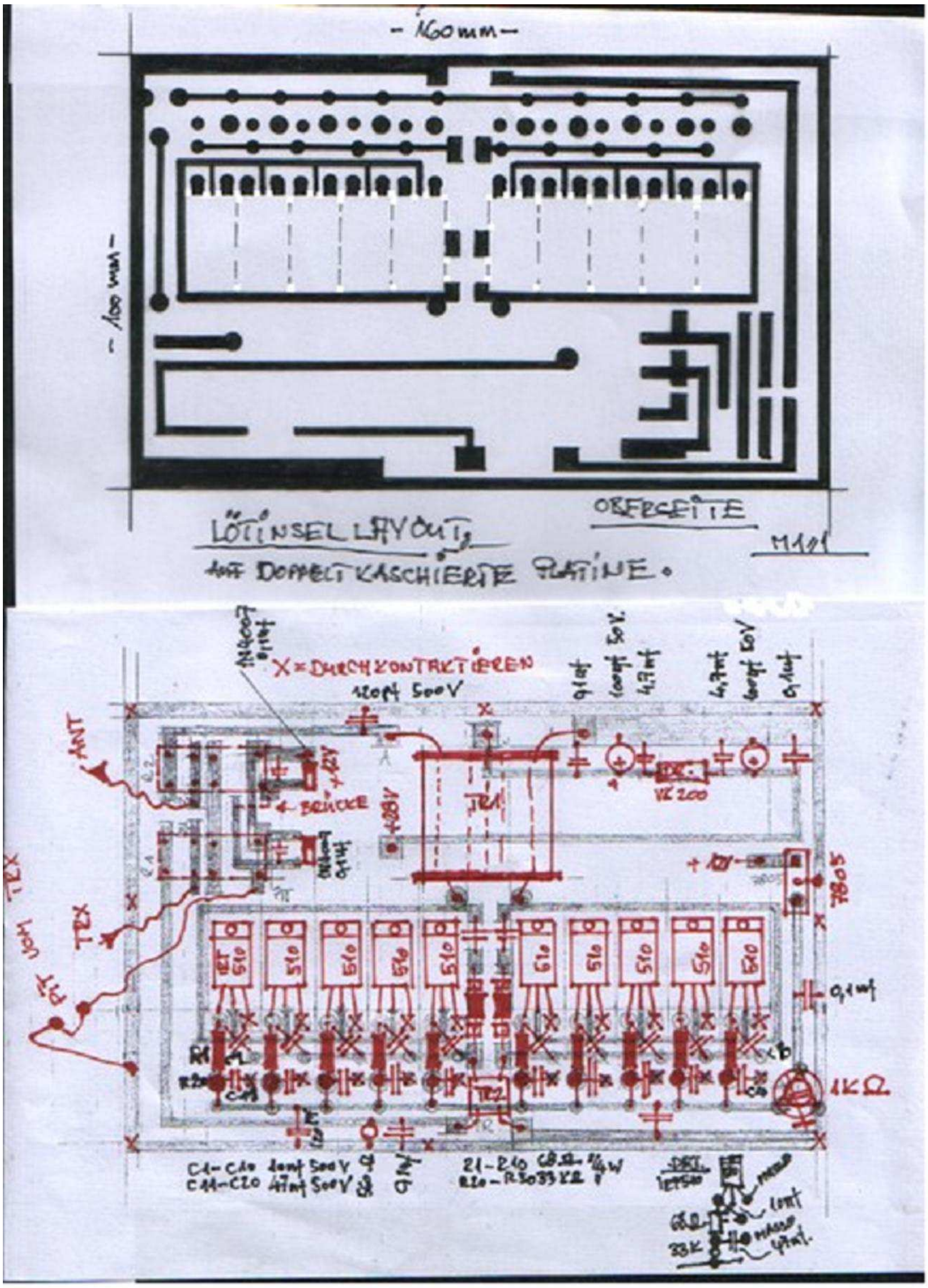
**Für den Abgleich ist der Biasstrom nach dem Poti gegen masse von 2,2 Volt
einzustellen. Die Ansteuerleistung vom TRX soll 2watt betragen bei einer
Spannungsversorgung der Endstufe mit 28 Volt. Es werden auf
160m und 10m ca. 70 Watt out und auf 12m bis 80m ca. 100 Watt out
erreicht.**

Der Kühlkörper ist entsprechend zu dimensionieren.

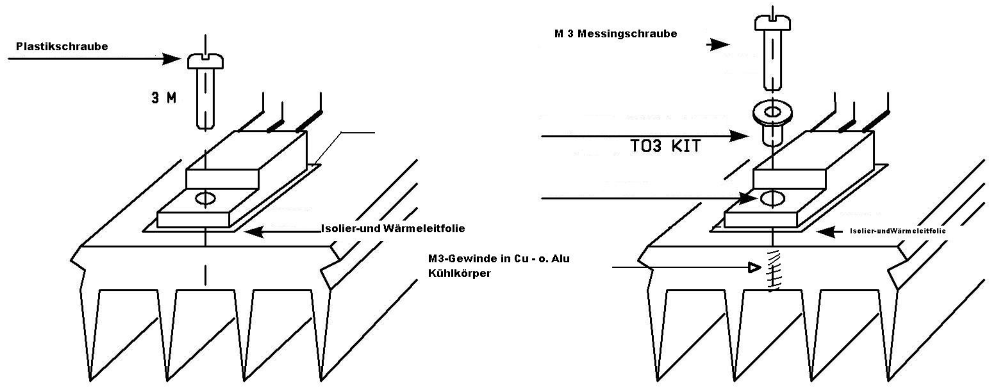
**Viel Erfolg beim Nachbau,
73 de do2sw - Wolfgang**

**Bauteile: Alle Bauteile sind bei Reichelt erhältlich:
Die Kosten für die Endstufe und die Filtereinheit betragen
ca.35.- Euro.
Kühlkörper und Platinenmaterial aus der Bastelkiste.**

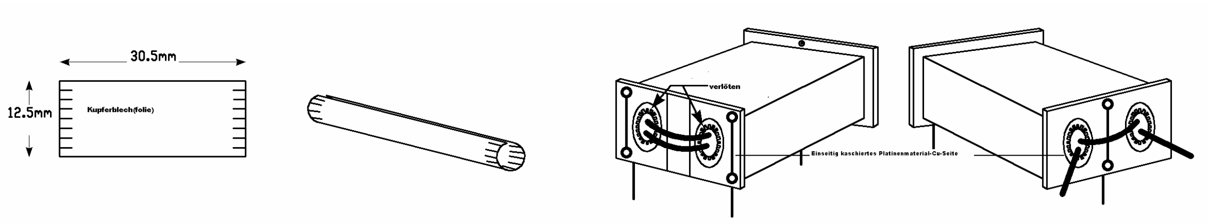
Platine mit Bestückungsskizze



Befestigung der Endstufentransistoren



Übertrager 1



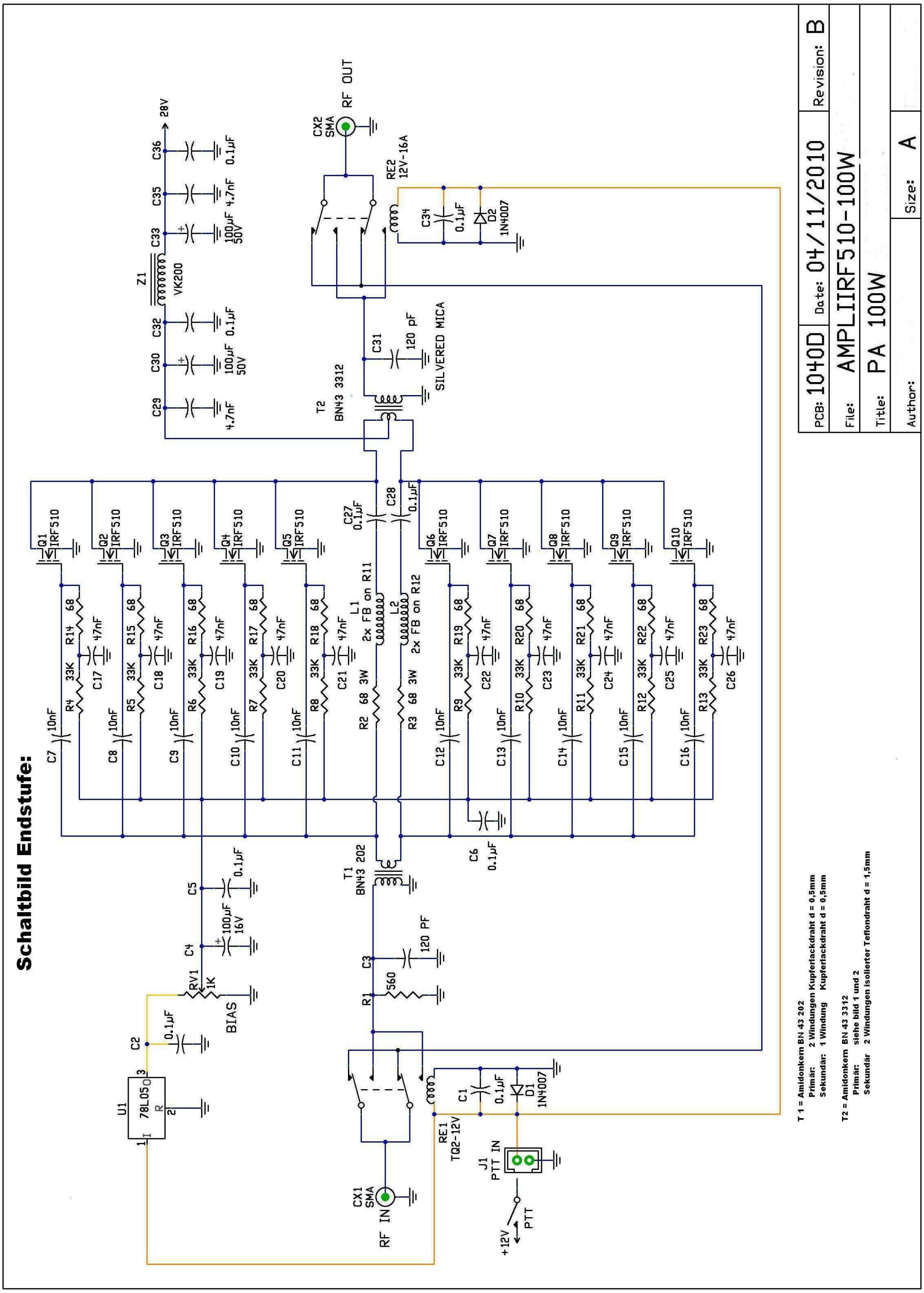
Stückliste

ELENCO COMPONENTI:

C10,C11,C14,C35,C36,C40,C42,C44	0.1µf
C12	120pF
C13	100µF 16V
C41	100µF 50V
C15….C24	10nF
C25….C34	47nF
C37,C43	4,7nF
C38	47µF 50V
C39	120pF mica argentata
R10	560Ω
R11,R12	68Ω 2W
R13….R22	33KΩ
R23….R32	68Ω
V10	Potenziometro da 1KΩ
D10,D11	1N4007
L10,L11 Induttanze ricavate inserendo due perline di ferrite sui reofori di R11 e R12	
L12	VK200
T10,T11	Vedi articolo
RE10,RE11	relè doppio scambio 16A 12V
U10	stabilizzatore 7805
Q1…Q10	IRF510
CX10	connettore BNC
CX11	connettore PL259

N.B. Le resistenze, ove non specificato, sono da 1/4 W.

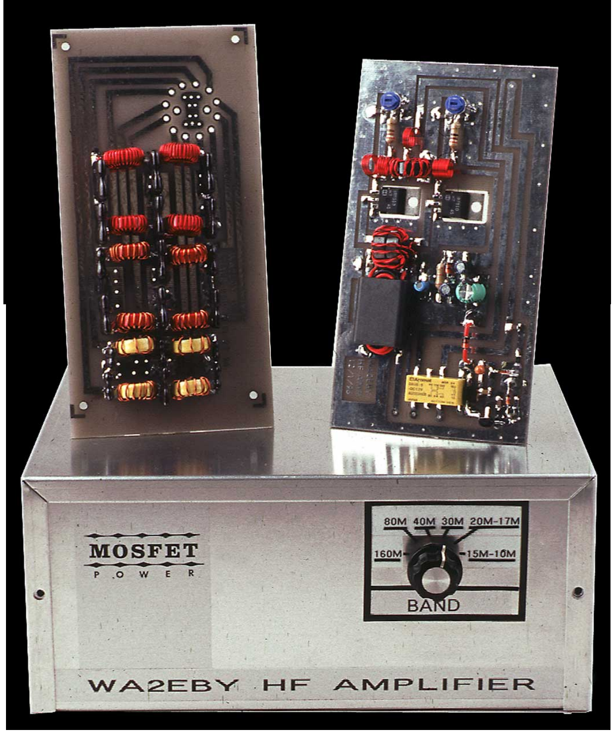
Schaltplan



Schaltbild Endstufe:
PCB: 1040D
Date: 04/11/2010
Revision: B
File: AMPLIIRF510-100W
Title: PA 100W
Size: A
Author:
RF OUT
RF IN
28V
+12V
PTT
BIAS
T 1 = Amidonkern BN 43 202
Primär: 2 Windungen Kupferlackdraht d = 0,5mm
Sekundär: 1 Windung Kupferlackdraht d = 0,5mm
T2 = Amidonkern BN 43 3312
Primär: siehe bild 1 und 2
Sekundär 2 Windungen isolierter Teflondraht d = 1,5mm

By Mike Kossor, WA2EBY

A Broadband HF Amplifier Using Low-Cost Power MOSFETs



Part 2—Let's put the finishing touches on this all-band HF amplifier!

Last month,[11] I covered the history and development of this 40 W (average) amplifier. I'm sure you're anxious to get your *amplifier finished and on the air, so let's get going!*

Amplifier Construction

The amplifier is constructed on a double-sided PC board with plated through holes to provide top-side ground connections. I used chip resistors and capacitors to simplify construction, but leaded capacitors may work if lead lengths are kept short. First, assemble all chip capacitors and resistors on the PC board. Tweezers help to handle chip components. Work with only one component value at a time (chip caps and resistors are very difficult to identify!). Chip capacitor and resistor mounting is simplified by tinning one side of the PC board trace with solder before positioning the capacitor or resistor. Touch the soldering iron tip to the capacitor or resistor to tack it in place. Finish mounting by soldering the opposite side of the component. *Don't apply too much heat to chip capacitors*. The metalized contacts on the capacitor can be damaged or completely removed if too much heat is applied. Use a 15 to 20 W soldering iron and limit soldering time to five seconds.

Mount axial-leaded resistors, diodes and remaining capacitors next. To avoid damaging them, mount inductors and transformers last. L1 and L2 are wound on a 0.25-inch drill-bit shaft. By wrapping the wire around the shaft 10 times, you'll get 9½ turns. The last turn arcs only a half-turn before entering the PC board. L3 is wound on a 0.190-inch diameter drill bit with 3½ turns wound the same way as L1 and L2. Mounting K1 is simplified by first bending all its leads 90° outward so it lies flat on the PC board. Use a wrist strap connected to ground through a 1 MΩ resistor to bleed off static body charge while handling MOSFETs, and do the work on an anti-static mat connected to ground via a 1 M Ω resistor. The gate input can be damaged by electrostatic discharge!

[11]Notes appear on page 46.

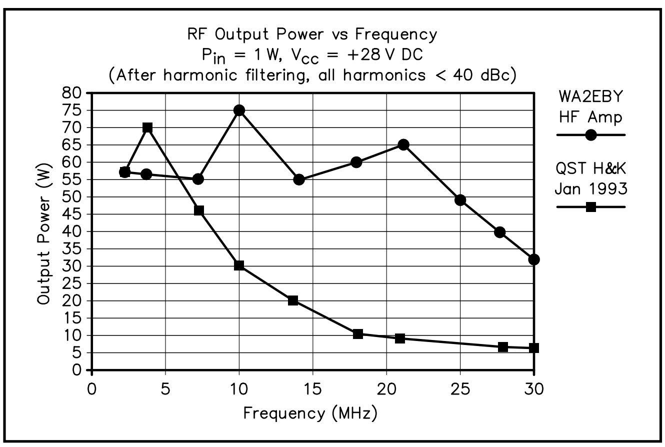


Figure 4—RF output power comparison of the Hint and Kink amplifier and this design.

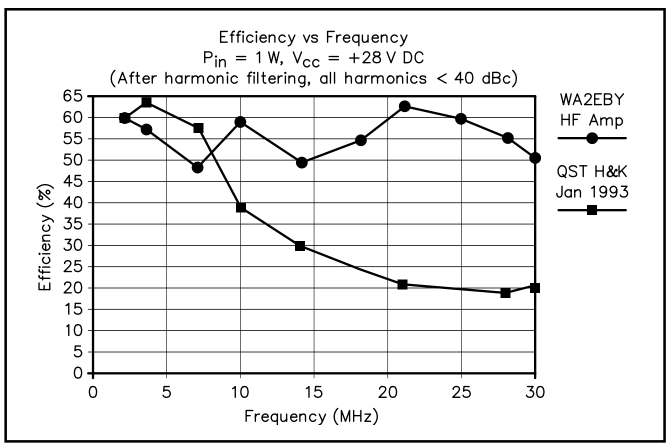


Figure 5—Efficiency comparison of the Hint and Kink amplifier and this one.

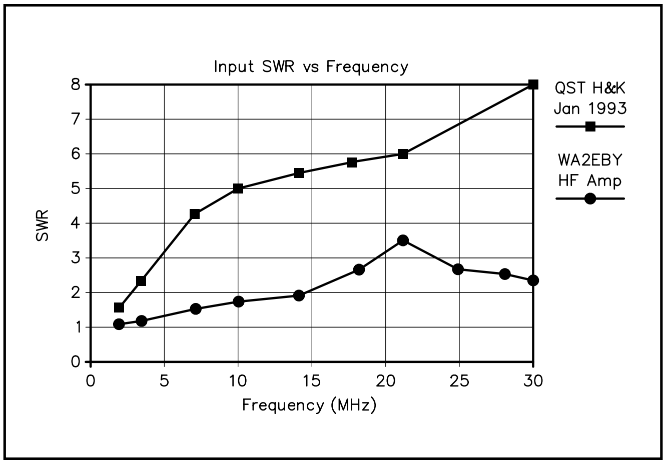


Figure 6—Input SWR comparison of the two amplifiers.

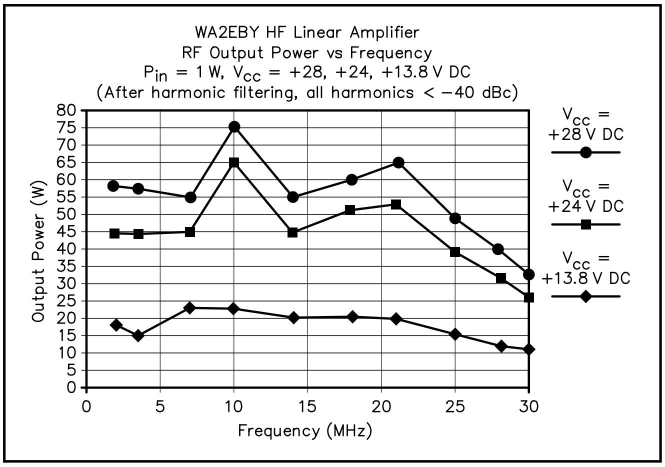


Figure 7—RF output power versus supply voltage of this amplifier.

When winding T3, wind the primary first and add the secondary winding over the primary. Be sure to use Teflon-insulated wire for T3's windings; the high operating temperatures encountered will likely melt standard hook-up wire insulation.

Heat Sinking

Together, Q1 and Q2 dissipate up to 59 W. A suitable heat sink is required to prevent the transistors from overheating and damage. I used an AAVID 244609B02 heat sink originally designed for dc-to-dc power converters. The amplifier PC board and heat sink are attached to an aluminum enclosure by two #4-40 screws drilled through the PC board, enclosure and heat sink at diagonally opposite corners. A rectangular cutout in the enclosure allows Q1 and Q2 direct access to the heat sink. This is essential because of the large thermal impedance associated with the TO-220 package (more on this topic later). Mark the locations of the transistor-tab mounting-hole location in the center of the heat sink in between the cooling fins. Disassemble the heat sink to drill 0.115 inch holes for #4-40 mounting screws, or tap #4-40 mounting holes in the center of the heat-sink fins.

Use mica insulators and grommets when mounting Q1 and Q2 to prevent the #4-40 mounting screws from shorting the TO-220 package drain connections (tabs) to ground. Coat both sides of the mica insulator with a *thin* layer of thermal compound to improve the thermal conduction between the transistor tab and the heat sink. Be sure to install the mica insulator on the heat sink *before* assembling the amplifier PC board to the enclosure and heat sink. The mica insulators are larger than the cut outs in the PC board, making it impossible to install them after the PC board is mounted.

Low-Pass Filter Construction

Inductor winding information for the low-pass filters is provided in Table 1.

Single Band

A PC-board trace is available on the amplifier PC board next to amplifier output (J3) to allow the installation of a single-band low-pass filter between the terminals of J3 and K1's input, J4. This is handy if you intend to use the amplifier on one band only. The input inductor of the low-pass filter connects from J3 to the single PC trace adjacent to J3. The output inductor connects in series between the single PC trace to J4. The three filter capacitors connect from J3, J4 and the PC-board trace near J3 to ground. *This single trace is not used when multiple filters are required*. Remember to remove the single trace adjacent to J3 on the amplifier PC board before attaching the amplifier board between the RF connectors on the enclosure's rear panel.

Multiple-Band Filters

Using the amplifier on more than one band requires a different approach. A set of six low-pass filters is built on a double-sided PC board with plated through holes to provide top-side ground connections. A PC-board mount, two-pole, six-position

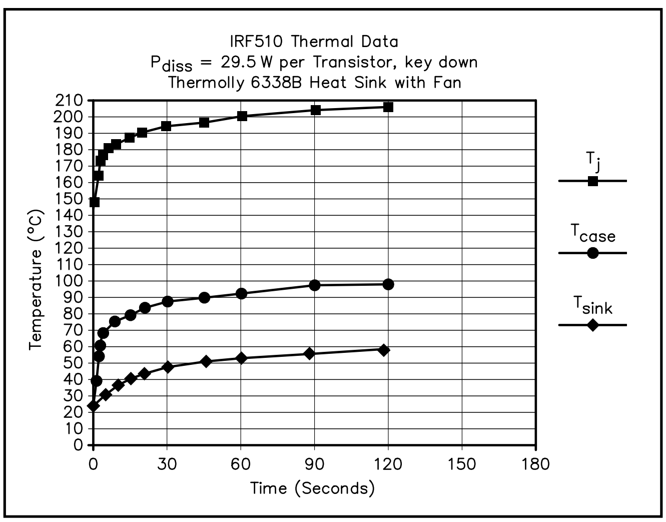


Figure 8—Thermal performance of the amplifier during key-down conditions.

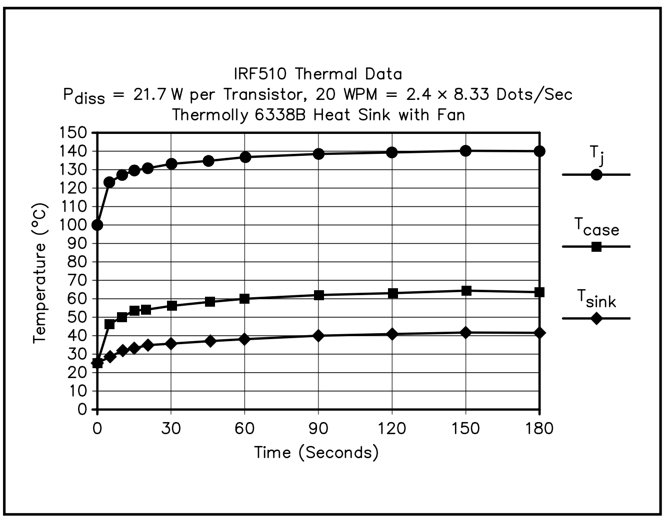


Figure 9—Thermal performance of the amplifier during simulated CW conditions.

rotary switch does all low-pass filter selection. Silver-mica, leaded capacitors are used in all the filters. On 160 through 30 meters, T-50-2 toroids are used in the inductors. T-50-6 toroids are used for inductors on 20 through 10 meters. The number of turns wound on a toroid core are counted on the toroid's OD as the wire passes through the core center (*The ARRL Handbook* [12] provides complete details for winding toroids). Assemble one filter section at a time starting with the 160, 80, 40-meter filter, then the 30-meter filter. With the switch mounting position at your upper left, the filter input (C1) is near the top edge of the board and the filter output (C3) is near the bottom edge. *The last two filters are out of sequence;* the 15-10 meter filter comes *before* the 20-17 meter filter) and the inputs/outputs are reversed to simplify the PC-board layout. The input capacitors, C13 and C16, are mounted on the board *bottom edge*, and output capacitors, C15 and C18, are on the *top edge*.

Use care when assembling the rotary switch. All 14 terminals must fit through the PC board without damaging or bending the pins. Make sure there are no bent pins before you attempt assembly. Insert the rotary switch into the PC board. Do *not* press the rotary switch all the way into the PC-board holes flush with the ground plane! If you do, the top flange of the signal pins may short to the ground plane.

Table 1
Low-Pass Filter Inductor Winding Information

(Refer to Figure 3 in Part 1)

Inductor Number	*No. of Turns*	*Core*
L1, L2	30 turns	T-50-2
L3, L4	22 turns	T-50-2
L5, L6	16 turns	T-50-2
L7, L8	14 turns	T-50-2
L9, L10	11 turns	T-50-6
L11, L12	8 turns	T-50-6

Note: All inductors are wound with #22 enameled wire except for L1–L4, which are wound with #24 enameled wire.

Bias Adjustment

The biasing procedure is straightforward and requires only a multimeter to complete. First, set R1 and R2 fully counterclockwise, (0 V on the gates of Q1 and Q2). Terminate the RF input and outputs with a 50 Ω load. Next, connect the 28 V supply to the amplifier in series with a multimeter set to the 0-200 mA current range. Measure and record the idling current drawn by the 5 V bias supply. The value should be approximately 9.5 mA (28 – 5.1 V) / 2.4 kΩ = 9.5 mA). Set Q1's drain current to 10 mA by adjusting R1 until the 28 V supply current increases by 10 mA above the idling current (9.5 + 10 = 19.5 mA). Next, adjust R2 for a Q2 drain current of 10 mA. This is accomplished by adjusting R2 until the 28 V supply current increases by an additional 10 mA (to 29.5 mA).

Amplifier Performance

With a 28 V power supply and 1 W of drive, the RF output power of this amplifier exceeds 40 W from 1.8 MHz through 28 MHz. Peak performance occurs at 10 MHz, providing about 75 W after filtering! A performance comparison between this amplifier and my modified version of the Hint and Kink amplifier mentioned earlier is shown in Figure 4.

As shown in Figure 5, this amplifier achieves an efficiency of better than 50% over its frequency range, except at 7 MHz where the efficiency drops to 48%. In contrast, the Hint and Kink amplifier delivers greater efficiency between 1.8 and 7 MHz, but it drops rapidly to only 20% as frequency is increased.

Figure 6 compares the input SWR of the two amplifiers. The Hint and Kink amplifier's SWR is acceptable (< 2:1) only at 1.8 MHz. This amplifier is better, however it, too, exceeds 2:1 above 14 MHz. The input SWR of this amplifier can be improved to better than 2:1 on all bands by adding a 3 dB pad (R8-R10 of Figure 2) at the input and supplying 2 W to the pad input. This keeps the amplifier drive at 1 W.

Figure 7 graphs this amplifier's RF output power as a function of drain supply voltage. During this test, the amplifier RF drive level was kept constant at 1 W. As you can see, even when using a 13.8 V dc supply, the amplifier provides over 10 W output (a gain of more than 10 dB) from 1.8 to 30 MHz.

Operation

The amplifier requires no tuning while operating on any HF amateur band. You must, however, *be sure to select the proper low-pass filter prior to transmitting*. If the wrong low-pass filter is selected, damage to the MOSFETs may result. Damage will likely result if you attempt to operate the amplifier on a band with the low-pass filter selected for a lower frequency. For example, driving the amplifier with a 21 MHz signal while the 1.8 MHz low-pass filter is selected will likely destroy Q1 and/or Q2.

The amplifier can also be damaged by overheating. This limitation is imposed by the TO-220 packages in which Q1 and Q2 are housed. The thermal resistance from junction to case is a whopping 3.5°C/W. This huge value makes it virtually impossible to keep the junction temperature from exceeding the +150°C target for good reliability. Consider the following conditions: key down, 1 W input, 53 W output on 7 MHz (worst-case band for efficiency). The amplifier consumes 28 V × 4 A = 112 W, of which 53 W are sent to the antenna, so 59 W (112 W – 53 W = 59 W) are dissipated in Q1 and Q2. Assuming equal current sharing between Q1 and Q2, each transistor dissipates 29.5 W. To keep the transistor junction temperature below +150°C requires preventing the transistor case temperature from exceeding 46.8°C (150 – [3.5 × 29.5]) while dissipating 29.5 W. Also, there is a temperature rise across the mica insulator between the transistor case and heat sink of 0.5°C/W. That makes the maximum allowable heat-sink temperature limited to 46.8 – (0.5 × 29.5) = 32°C. In other words, the heat sink must dissipate 59 W (29.5 from each transistor) with only a 7°C rise above room temperature (25°C). Even if the junction temperatures were allowed to reach the absolute maximum of 175°C, the heat sink temperature must not exceed 57°C. Accomplishing this requires a heat sink with a thermal resistance of (57 – 25) / 59 = 0.54°C/W. This is far less than the 1.9°C/W rating of the AAVID 244609B02 heat sink I used. The situation may seem bleak, but all is not lost. These calculations make it clear that the amplifier should not be used for AM, FM or any other continuous-carrier operation. The amplifier should be used only for CW and SSB operation where the duty cycle is significantly reduced.

Thermal performance of the amplifier is illustrated in Figure 8. Data was taken under dc operating conditions with power-dissipation levels set equal to conditions under RF operation. A RadioShack brushless 12 V dc fan (RS 273-243A) blows air across the heat sink. Key down, the maximum rated junction temperature is reached in as little as five seconds as illustrated in Figure 8. Prolonged key-down transmissions should be avoided for this reason.

Under intermittent CW conditions, the situation is very different. Transistor-case temperatures reached 66°C after operating four minutes under simulated CW conditions at 20 WPM (60 ms on, 60 ms off). The corresponding junction temperature is +141°C (based on an equivalent RMS power dissipation of 21.7 W per transistor). This keeps the junction temperature under the 150°C target (see Figure 9). One simple way to reduce power dissipation is to reduce the power-supply voltage to 24 V. RF output power will decrease about 10 W from the maximum levels achieved with a 28 V supply.

From a thermal standpoint, the IRF510 power MOSFET is a poor choice for this RF amplifier application. Although I must say I am impressed with the robustness of these devices considering the times I spent testing them key down, five minutes at a time, without failure. Q1 and/or Q2 may need to be replaced after a year or so of operation because of the compromise in reliability. Considering their low cost, that is not a bad trade-off.

Stability

High gain, broad bandwidth and close input/output signal routing (within the TR relay) all work against stability. With a good load (< 2:1 SWR) the amplifier is stable from 1.8 MHz through 39 MHz. Oscillation was observed when the transmitter frequency was increased to 40 MHz. The output load match also affects stability. Oscillation was observed on 27.5 MHz when the load SWR was 3:1. This should not be a problem since the frequency is outside the ham bands. I spent a great deal of time trying to make this design unconditionally stable even with loads exceeding 3:1 SWR without sacrificing output power (gain) at 28 MHz without success. I did identify some reasonable compromises.

One of the easiest ways to improve stability and the input SWR seen by the RF source is to add an RF attenuator (pad) at the amplifier input. An attenuator is absolutely required if the transmitter (driver) provides more than 1 W to the amplifier. R8, R9 and R10 form an RF attenuator that attenuates the transmitter drive level, but does not attenuate received signals because it is only in the circuit when K1 is energized. To drive this amplifier with a 2-W-output transmitter requires use of a 3-dB pad. The pad improves the amplifier input SWR and the isolation between the amplifier's input and output. The drawback is that 1 W is wasted in the pad. Likewise, a 5-W driver requires use of a 7-dB pad, but 4 W are wasted in the pad. (Values for R8, R9 and R10 to make a 3-dB pad and a 7-dB pad are given in the parts list.) Installing a pad requires cutting the PC-board trace *under R9*, otherwise R9 would be shorted out by the trace. Make a small cut (0.1 inch wide) in the trace under R9 before soldering R9 in position. R8 and R10 have the same values, but may have different power ratings. Connect R10 between the RF input side of R9 and ground. Install R8 between the amplifier side of R9 and ground.

An impedance mismatch between the output of a 1-W-output driver and the amplifier input can be a source of instability. (Obviously, if the driving transmitter's output power is only 1 W, you can't use a pad as described earlier.) If you encounter stability problems, try these remedies: Place a resistor in parallel with L1 and L2 to decrease the Q of the amplifier matching network (try values between 50 and 220 Ω). Try reducing the value of L3 or eliminating L3 entirely. Both of these modifications improve stability, but reduce the amplifier's output power above 21 MHz.

Summary

This project demonstrates how inexpensive power MOSFETs can be used to build an all-band linear HF power amplifier. Frequency of operation is extended beyond the limits of previous designs using the IRF510 and improved input-impedance matching. Long-term reliability is recognized as a compromise because of the poor thermal performance of the low-cost TO-220 package.

If you have been thinking about adding an amplifier to your QRP station, this project is a good way to experiment with amplifier design and is an excellent way to become familiar with surface-mount "chip" components. I made arrangements with Mouser Electronics and Amidon Inc to provide parts kits for this project at a discounted price (see the parts list in Part 1). These parts kits make it very easy to get started and more economical to "homebrew" this project.

Acknowledgments

I want to thank the following individuals associated with this project: Harry Randel, WD2AID, for his untiring support in capturing the schematic diagram and parts layout of this project; Al Roehm, W2OBJ, for his continued support and encouragement in developing, testing, editing and publishing this project; Larry Guttadore, WB2SPF, for building, testing and photographing the project; Dick Jansson, WD4FAB, for thermal-design suggestions; Adam O'Donnell, N3RCS, for his assistance building prototypes; and my wife, Laura, N2TDL, for her encouragement and support throughout this project.

Notes

[11] Mike Kossor, "A Broadband HF Amplifier Using Low-Cost Power MOSFETs—*Part 1*," *QST,* Mar 1999, pp 40-43.

[12] R. Dean Straw, N6BV, *The 1999 ARRL Handbook for Radio Amateurs*, (Newington: ARRL), 76th ed, pp 25-23*ff*.

Strays

I would like to get in touch with...

◊...hams who have lived and worked on Kwajalein Atoll, Marshall Islands. I'd like to set up a meeting at the Hawaii Kwaj Reunion in 2000 and build a database of Kwaj hams. Contact Bernard Fineberg, AB7HB (ex-KX6AG, V73I) at **fineberg@oregontrail.net** or PO Box 208, Irrigon, OR 97844-0208.

◊... the ham who worked with me to build the radio-controlled Comet sailplane model that was flown in the 1940 and 1941 AMA National contests in Chicago. Bob Reder, 2104 Valley Lo Lane, Glenview, IL 60025.

◊...anyone who has an operating manual for a TRACOR rubidium frequency standard Model 600A (preferred), or for model 304B, C, or D. Tom Barton, **thbarton@worldnet.att.net**; tel 212-292-4444.

◊...other radio amateurs of the Seventh-Day Adventist faith. Contact me at **kw8t@cwix.com**, or write to 58 Byron Dr, Smithsburg, MD 21783-1565. Jim Hoffer, KW8T.

◊...anyone who has specifications for the ADI/Pryme AT-600HP dual-band radio so that I can make my own programming interface. Please e-mail W6NCT at **w6nct@hotmail.com**.

◊...anyone who has QSLs from my father, William (Bill) Prater, W5BLT. He became a Silent Key in April 1978. I've been able to obtain my father's call sign thanks to the vanity call program and I am trying to find his old QSLs or any other materials in order to establish my (our) call heritage. Please contact me via e-mail at **w5blt@ix.netcom.com**. Bob Prater, W5BLT.

WORKED ALL TEXAS

◊ The Temple Amateur Radio Club is sponsoring the Worked All Texas Award for amateurs who make contacts with stations in Texas counties. There are five certification levels: 50 counties, 100 counties, 150 counties, 200 counties and 254 counties. Holders of the CQ USA-CA award automatically qualify (submit USA-CA award number with date the award was achieved). All others must submit a list of counties along with the call signs of stations worked in each county. The entry must include the signatures of three nonrelated hams. They are to witness the QSL cards or MRCs that confirm the QSO with the stations in the counties being claimed. For more information and a list of Texas counties, send an SASE to: Worked All Texas Award, c/o Temple Amateur Radio Club, PO Box 616, Temple, TX 76503, or visit their Web site at **http://www.tarc.org**.

Next Stray

New Products

NEW LIGHTNING SURGE PROTECTOR FROM DYNAMIC ELECTRONICS

◊ The LP-1 lightning surge protector uses a normally closed 12 V relay in a metal enclosure to automatically short the center conductor of your coax feedline to ground when your station is not in use. 12 V to open the relay for normal operation can be provided by the 12 V accessory output on the back of many current transceivers or by connection to your main 12 V station supply. An RCA type phono cable for power and 3 feet of RG-58U with PL-259 connectors are included. The LP-1 is designed for use from 160 to 2 meters. For more information contact Dynamic Electronics Inc, PO Box 896, Hartselle, AL 35640; tel 256-773-2758, fax 256-773-7295, **dei@whnt19.com**, **http://www.hsv.tis.net/~dei**. Price: $39.95 plus $4 s/h.

Next New Product

By Mike Kossor, WA2EBY

A Broadband HF Amplifier Using Low-Cost Power MOSFETs

Part 1—With only 1 W of drive, you'll get over 40 W out—from 160 through 10 meters!

Many articles have been written encouraging experimenters to use power MOSFETs to build HF RF amplifiers. That's because power MOSFETs—popular in the design of switching power supplies—cost as little as $1 each, whereas RF MOSFET prices start at about $35 each!

Over the years, I tucked away several of these articles, waiting for an opportunity to experiment with them. That opportunity came when I received a call from Al, W2OBJ. Al wanted a low-cost linear amplifier to use with his 5 W QRP transmitter when band conditions got poor. Ideally, the amplifier would generate at least 25 W on all the HF bands. Al's inquiry renewed my interest in the topic and provided the motivation I needed to get my project underway.

Al provided me with an extensive list of RF-amplifier construction articles that use power MOSFETs.[1-8] These articles provided useful information about MOSFETs and general guidelines for working with them, including biasing, parasitic-oscillation suppression, broadband impedance-matching techniques and typical amplifier performance data. It was clear from the performance data that Al's desire to get 25 W output from power MOSFETs on 1.8 to 30 MHz was going to be a challenge! The RF output power of most of the amplifiers described in the articles drops off to 10 W or less as frequency increases just to 14 MHz.

An Idea Brews

After hundreds of hours of experimentation, I came up with a design that exceeds our original objective: One watt of input power produces over 40 W of output (after harmonic filtering) from 160 through 10 meters. To the basic amplifier, I added an RF-sensed TR relay and a set of low-pass filters designed to suppress harmonic output and comply with FCC requirements. The amplifier is built on double-sided PC board and requires *no tuning*. Another PC board contains the low-pass filters. Power-supply requirements are 28 V dc at 5 A, although the amplifier performs well at 13.8 V dc.

Several of these amplifiers have been built and exhibit similar performance. Al has been using his amplifier on each of the HF bands, logging well over 500 contacts in 18 months. Signal reports indicate a noticeable improvement in readability (about two S units on average) over his 5 W rig. No indications of instability, CW key clicks or distortion on SSB have been reported. To make it easy for you to duplicate this project, PC boards and parts kits are available, all at a cost of about $100![9]

An Overview of MOSFETs

MOSFETs operate very differently from bipolar transistors. MOSFETs are voltage-controlled devices and exhibit a very high input impedance at dc, whereas bipolar transistors are current-controlled devices and have a relatively low input impedance. Biasing a MOSFET for linear operation only requires applying a fixed voltage to its gate via a resistor. With MOSFETs, no special bias or feedback circuitry is required to maintain the bias point over temperature as is required with bipolar transistors to prevent thermal runaway.[10] With MOSFETs, the gate-threshold voltage increases with increased drain current. This works to turn off the device, especially at elevated temperatures as transconductance decreases and $R_{DS(on)}$ (static drain-to-source *on* resistance) increases. These built-in self-regulating actions prevent MOSFETs from being affected

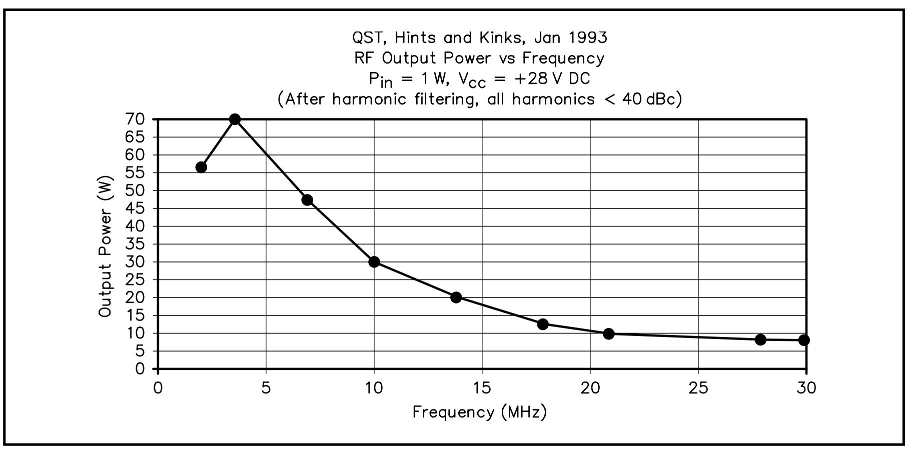


Figure 1—Jim Wyckoff, AA3X, "1 W In, 30 W Out With Power MOSFETs at 80 M," Hints and Kinks, *QST*, Jan 1993, pp 50-51.

[1]Notes appear on page 43.

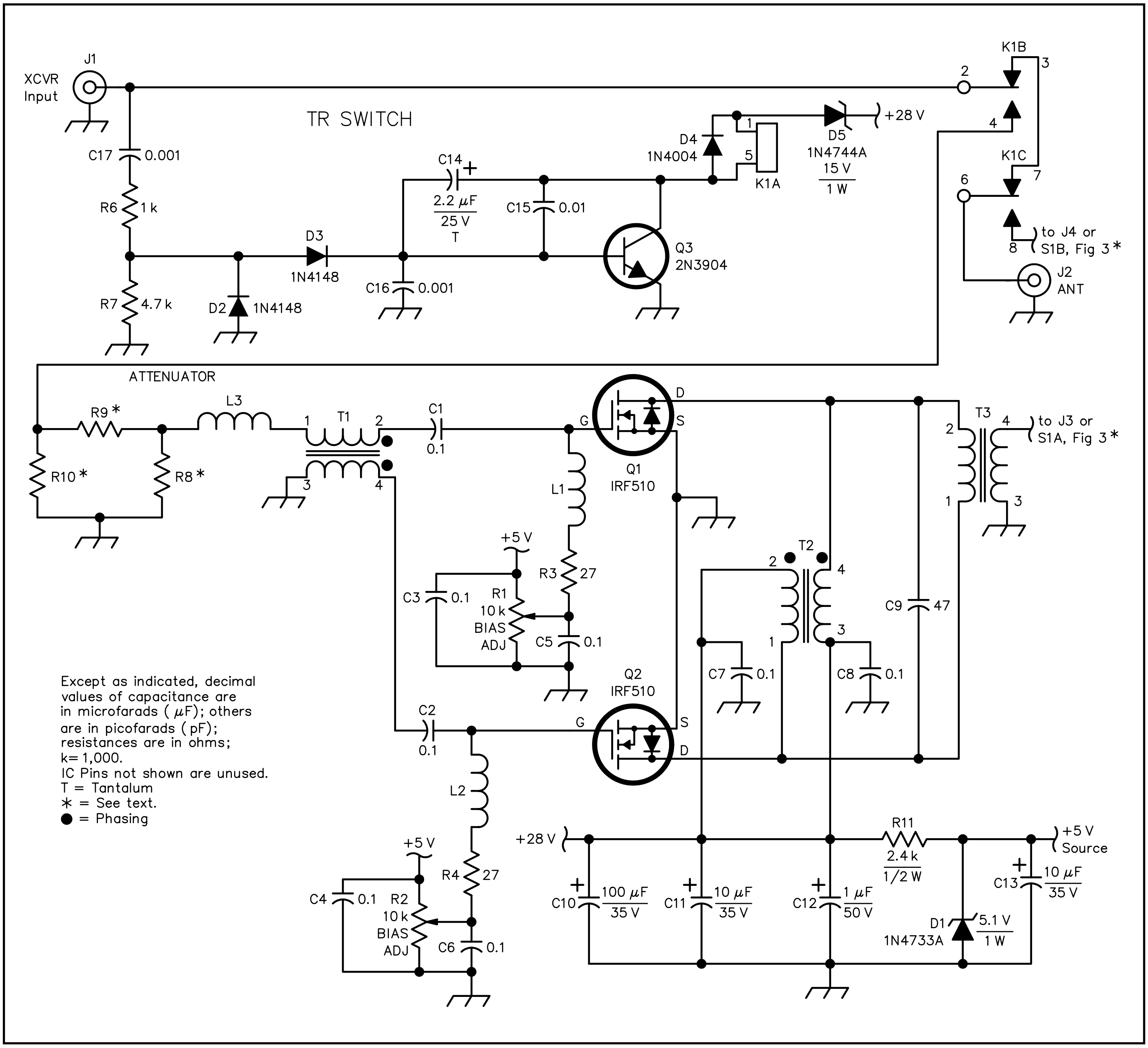
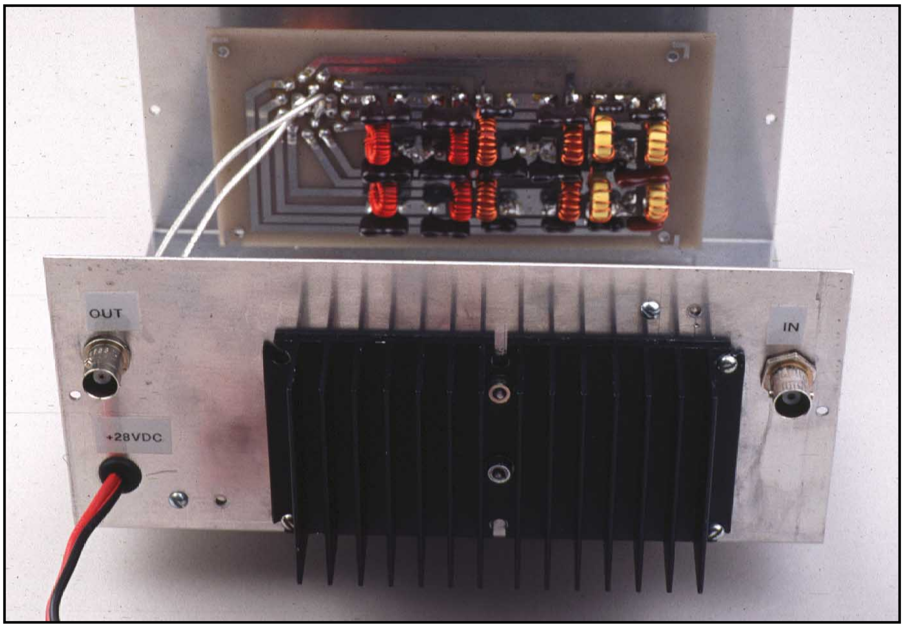


Figure 2—Schematic of the MOSFET all-band HF amplifier. Unless otherwise specified, resistors are 1/4 W, 5% tolerance carbon-composition or film units. Equivalent parts can be substituted. Part numbers in parentheses are Mouser (Mouser Electronics, 968 N Main St, Mansfield, TX 76063; tel 800-346-6873, 817-483-4422, fax 817-483-0931; **sales@ mouser.com**; **http://www.mouser.com**); see Note 9.

C1-C8—0.1 µF chip (140-CC502Z104M)
C9—47 pF chip (140-CC502N470J)
C10—100 µF, 35 V (140-HTRL35V100)
C11, C13—15 µF, 35 V (140MLR35V10)
C12—1 µF, 50 V (140-MLRL50V1.0)
C14—2.2 µF, 35 V tantalum (581-2.2M35V)
C15—0.01 µF chip (140-CC502B103K)
C16, C17—0.001 µF chip (140-CC502B102K)
D1—1N4733A, 5.1 V, 1 W Zener diode (583-1N4733A)
D4—1N4004A(583-1N4004A)
D2, D3—1N4148 (583-1N4148)
D5—1N4744A, 15 V, 1 W Zener diode (583-1N4744A)
J1, J2—SO-239 UHF connector (523-81-120)
K1—12 V DPDT, 960 Ω coil, 12.5 mA (431-OVR-SH-212L)
L1, L2—9 1/2 turns #24 enameled wire, closely wound 0.25-in. ID
L3—3 1/2 turns #24 enameled wire, closely wound 0.190-in. ID
Q1, Q2—IRF510 power MOSFET (570-IRF510)
Q3—2N3904 (610-2N3904)
R1, R2—10 kΩ trim pot (323-5000-10K)
R3, R4—27 Ω, 1/2 W (293-27)
R6—1 kΩ chip (263-1K)
R7— 4.7 kΩ chip (263-4.7K)
R8—130 Ω, 1 W (281-130); for 7 dB pad (5 W in, 1 W out)
R9—43 Ω, 2 W (282-43); for 7 dB pad (5 W in, 1 W out)
R10—130 Ω, 3 W (283-130); for 7 dB pad (5 W in, 1 W out)
R8, R10—300 Ω, 1/2 W (273-300); for 3 dB pad (2 W in, 1 W out)
R9—18 Ω, 1 W (281-18); for 3 dB pad (2 W in, 1 W out)
R11—2.4 kΩ, 1/2 W (293-2.4K)
T1—10 bifilar turns #24 enameled wire on an FT-50-43 core.
T2—10 bifilar turns #22 enameled wire on two stacked FT-50-43 cores.
T3—Pri 2 turns, sec 3 turns #20 Teflon-covered wire on BN-43-3312 balun core.
Misc: Aluminum enclosure 3.5×8×6 inches (HWD) (537-TF-783), two TO-220 mounting kits (534-4724), heat-sink compound (577-1977), amplifier PC board (see Note 9), heat sink (AAVID [Mouser 532-244609B02]; see text), about two feet of RG-58 coax, #24 enameled wire and #20 Teflon-insulated wire.



A rear panel view of the amplifier showing the heat sink.

by thermal runaway. MOSFETs do not require negative feedback to suppress low-frequency gain as is often required with bipolar RF transistors. Bipolar transistor gain increases as frequency decreases. Very high gain at dc and low frequencies can cause unwanted, low-frequency oscillation to occur in bipolar transistor RF amplifiers unless negative feedback is employed to prevent it. Low-frequency oscillation can damage bipolar transistors by causing excess power dissipation, leading to thermal runaway.

MOSFET Limitations

Of course, MOSFETs do have their limitations. The high gate impedance and the device structure make them susceptible to electrostatic discharge (ESD) damage. Some easily applied precautions prevent this: Use a soldering iron with grounded tip; use a wrist strap connected to ground through a 1 MΩ resistor to bleed off excess body charge while handling MOSFETs and do all work on an anti-static mat connected to ground via a 1 MΩ resistor.

The sensitivity of a MOSFET's gate to static and high-voltage spikes also makes it vulnerable to damage resulting from parasitic oscillation. This undesired self-oscillation could result in excessive gate-to-source voltage that permanently damages the MOSFET's gate insulation. Another MOSFET limitation is gate capacitance. This parameter limits the frequency at which a MOSFET can operate effectively as an RF amplifier. I recommend reviewing the referents of Notes 1, 2 and 3 if you are interested in more detailed information about MOSFETs.

Power MOSFET RF Amplifiers

Of the several power MOSFET amplifiers I built to check their performance, the one providing the best performance is the push-pull design described by Jim Wyckoff, AA3X, in *QST* (see Note 3). I used IRF510 power MOSFETs rather than the IRF511s specified. The performance of this power MOSFET amplifier design is summarized in Figure 1; its basic design is very similar to another amplifier described in the referent of Note 4, written 10 years earlier. That amplifier uses a pair of more-expensive MRF138 MOSFETs designed specifically for RF applications.

As Figure 1 shows, the Hints and Kinks amplifier performance is excellent from 1.8 MHz to 7 MHz and far exceeds the published figure of 30 W output on 3.5 MHz. As frequency increases above 10 MHz, however, output drops off rapidly, falling below 10 W above 21 MHz. (These levels were measured after harmonic filtering.)

Although the amplifier is identified as stable, my first attempt at duplicating the amplifier resulted in oscillations that destroyed one of the IRF510s. I was puzzled by this. At first, I thought the problem was caused by my substitution of the slightly more robust IRF510 MOSFETs for the called-for IRF511s. That idea proved wrong when my second attempt to power up the amplifier with IRF511 MOSFETs installed also resulted in a blown IRF511. (Thank goodness these are $1 power MOSFETs, not $35 RF MOSFETs!) I finally achieved good stability when I added a small amount of inductance in series with the MOSFET source to ground (just two turns of #24 wire, 0.125 inch diameter). With this added inductance, I was able to remove the ferrite beads from the circuit without any sign of instability. I believe the substitution of the IRF510 and minimizing source lead inductance are the reasons I obtained significantly higher RF output power and wider bandwidth than described in the referent of Note 3. This experiment underscores the need to observe *exact* construction techniques and physical layout if similar performance is to be expected. Even though I used PC board construction, I got significantly different results because my layout was not the same as the author's.

Modifying the Design

Although the amplifier performed better than expected, its bandwidth was significantly less than desired. Considerable experimentation (and I do mean considerable!) resulted in the circuit shown in Figure 2. This amplifier consists of two power MOSFETs operating in push-pull and employs an RF-sensed TR relay.

During receive, TR relay K1 is deenergized. Signals from the antenna are connected to J2 and routed through K1 to a transceiver connected to J1. (This path loss is less than 0.3 dB from 1.8 MHz through 30 MHz.) In transmit, RF voltage from the transceiver is sampled by C17 and divided by R6 and R7. D2 and D3 rectify the RF voltage and charge C16. Q3 begins conducting when the detected RF voltage across C16 reaches approximately 0.7 V. This energizes K1, which then routes the transmitted RF signal from J1 to the input of the amplifier and sends the output of the amplifier to the antenna at J2. RF-sensed relay response is very fast. No noticeable clipping of the first CW character has been reported.

I made provisions to include an RF attenuator (consisting of R8, R9 and R10) to enable adjusting the amplifier iput power to 1 W. (The parts list contains resistor values to reduce the output of 2 or 5 W drivers to 1 W.) The 1 W signal is then applied to the primary of T1 via an input impedance-matching network consisting of L3. T1 is a 1:1 balun that splits the RF signal into two outputs 180 degrees out of phase. One of these signals is applied by C1 to Q1's gate. The other signal is routed via C2 to Q2's gate. The drains of Q1 and Q2 are connected to the primary of output transformer T3, where the two signals are recombined in phase to produce a single output. T3 also provides impedance transformation from the low output impedance of the MOSFETs to the 50 Ω antenna port. Dc power is provided to the drains of Q1 and Q2 by phase-reversal choke, T2. This is a very effective method to provide power to Q1 and Q2 while presenting a high impedance to the RF signal over a broad range of frequencies. The drain chokes for Q1 and Q2 are wound on the same core, and the phase of one of the chokes (see the phasing-dot markings on T2) is reversed. C9 increases the bandwidth of impedance transformation provided by T3, especially at 21 MHz.

The 5 V bias supply voltage is derived from 28 V by Zener diode D1 and current-limiting resistor R11. Bypass capacitors C3, C4, C5, C6 and C13 remove RF voltages from the bias supply voltage. Gate bias for Q1 and Q2 is controlled independently. R1 adjusts Q1's gate-bias voltage via R3 and L1. R2 works similarly for Q2 via R4 and L2.

At low frequencies, the amplifier's input impedance is essentially equal to the series value of R3 and R4. L1 and L2 improve the input-impedance match at higher frequencies. The low value of series resistance provided by R3 and R4 also reduces the Q of

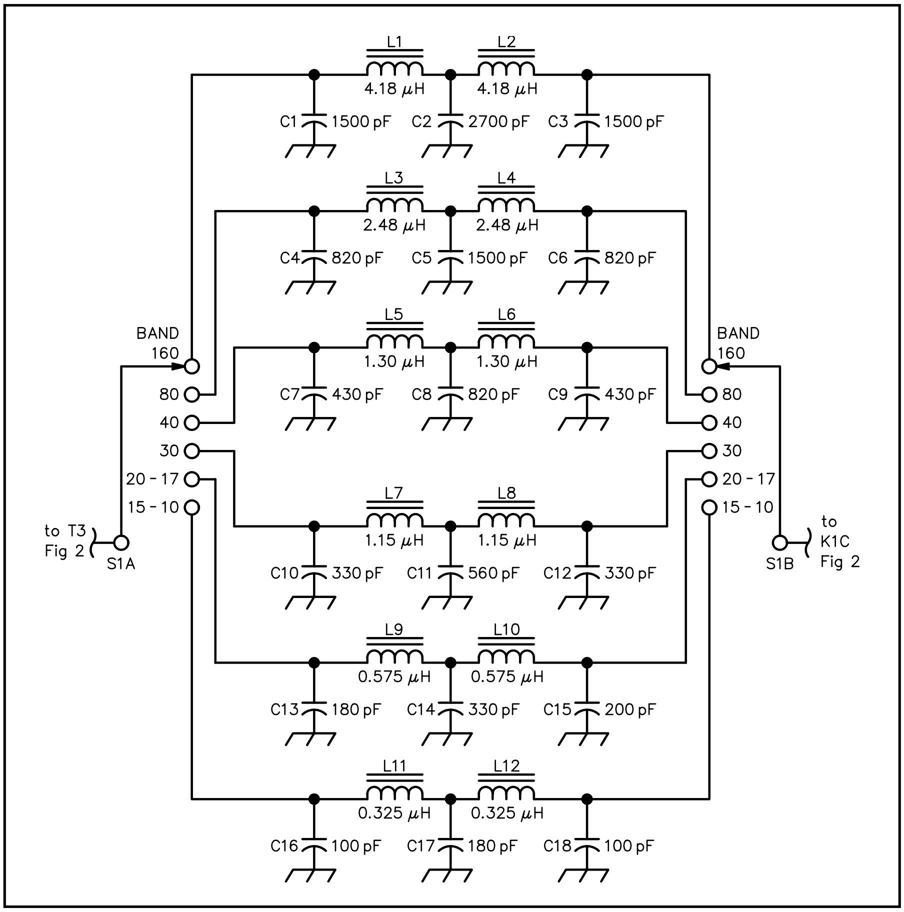


Figure 3—Low-pass filter schematic. In some cases, the actual filter component values differ from the calculated values of a standard 50 Ω-input filter. Such differences improve the impedance matching between the amplifier and the load. Capacitors are all dipped mica units.

C1, C3, C5—1500 pF (5982-19-500V1500)
C2—2700 pF (5982-19-500V2700)
C4, C6, C8—820 pF (5982-19-500V820)
C7, C9—430 pF (5982-15-500V430)
C10, C12, C14—330 pF (5982-19-500V330)
C11—560 pF (5982-19-500V560)
C13, C17—180 pF (5982-15-500V180)
C15—200 pF (5982-15-500V200)
C16, C18—100 pF (5982-10-500V100)
S1—2 pole, 6 position rotary (10YX026)
Misc: low-pass filter PC board (see Note 9)

impedance-matching inductors L1 and L2, which improves stability. Dc blocking capacitors C1 and C2 prevent loading the gate bias-supply voltage.

C14 keeps transistor Q3 conducting and K1 energized between SSB voice syllables or CW elements. Without C14, K1 would chatter in response to the SSB modulation envelope and fast keying. Increasing the value of C14 increases the time K1 remains energized during transmit. The reverse voltage generated by K1 when the relay is deenergized is clamped to a safe level by D4. D5 drops the 28 V supply to 13 V to power 12 V relay K1. D5 can be replaced with a jumper if K1 has a 28 V dc coil or if you intend to operate the amplifier with a 13.8 V dc supply.

Harmonic Filtering

Although biased for class AB linear operation, this amplifier (like others of its type) exhibits some degree of nonlinearity, resulting in the generation of harmonics. This push-pull amplifier design cancels even-order harmonics (2f, 4f, 6f, etc) in the output transformer, T3. Odd-order harmonics are not canceled. Second-order harmonics generated by the amplifier are typically less than 30 dBc (30 dB below the carrier) whereas third-order harmonics are typically only 10 dBc. FCC regulations require all HF RF-amplifier harmonic output power to be at least 40 dBc at power levels between 50 to 500 W. To meet this requirement, it is common practice for HF amplifiers to use low-pass filters. Separate low-pass filters are needed for the 160, 80, 40 and 30 meter bands. The 20 and 17 meter bands can share the same low-pass filter. So, too, the 15, 12 and 10 meter bands can share a common low-pass filter; see Figure 3.

Switching among the six filters can be a messy wiring problem, especially on the higher-frequency bands where lead lengths should be kept short for optimum performance. This problem is solved by mounting all six low-pass filters on a PC board. A two-pole, six-position rotary switch (S1) mounted directly on the same PC board manages all filter interconnections. One pole of S1 connects the amplifier output to one of the six filter inputs, while S1's other pole simultaneously connects the corresponding filter's output to the TR relay, K1. Only two coaxial-cable connections are required between the RF amplifier and the low-pass filter board.

Next Month

In Part 2, I'll wrap up with amplifier construction and adjustment, and discuss the amplifier's overall performance. See you then!

Notes

[1]Doug DeMaw, W1FB, "Power-FET Switches as RF Amplifiers," *QST*, Apr 1989, pp 30-33. See also Feedback, *QST*, May 1989, p 51.

[2]Wes Hayward, W7ZOI, and Jeff Damm, WA7MLH, "Stable HEXFET RF Power Amplifiers," Technical Correspondence, *QST*, Nov 1989, pp 38-40; also see Feedback, *QST*, Mar 1990, p 41.

[3]Jim Wyckoff, AA3X, "1 Watt In, 30 Watts Out with Power MOSFETs at 80 Meters," Hints and Kinks, *QST*, Jan 1993, pp 50-51.

[4]Doug DeMaw, W1FB, "Go Class B or C with Power MOSFETs," *QST*, March 1983, pp 25-29.

[5]Doug DeMaw, W1FB, "An Experimental VMOS Transmitter", *QST*, May 1979, pp 18-22.

[6]Wes Hayward, W7ZOI, "A VMOS FET Transmitter for 10-Meter CW," *QST*, May 1979, pp 27-30.

[7]Ed Oxner, ex-W9PRZ (SK), "Build a Broadband Ultralinear VMOS Amplifier," *QST*, May 1979, pp 23-26.

[8]Gary Breed, K9AY, "An Easy-to-Build 25-Watt MF/HF Amplifier," *QST*, Feb 1994, pp 31-34.

[9]Parts for this project are available in five modular kits. The following three kits are available from Mouser Electronics (Mouser Electronics, 958 N Main St, Mansfield, TX 76063; tel 800-346-6873, 817-483-4422, fax 817-483-0931; **sales@mouser.com**; **http://www.mouser.com**): Amplifier components (Mouser P/N 371-HFAMP1) consisting of the amplifier PC board and all PC-board-mounted components (except for the ferrite cores). Price: $35, plus shipping. Amplifier hardware kit (Mouser P/N 371-HFAMP2) consisting of the aluminum enclosure, two UHF connectors, two TO-220 mounting kits, AAVID heat sink and one container of heat sink compound. Price: $30 plus shipping. Low-pass filter kit (Mouser P/N 371-HFAMP3) consisting of the low-pass filter PC board, rotary switch and all PC-board-mounted capacitors (inductor cores are *not* included). Price: $35, plus shipping. Part-placement diagrams accompany the PC boards.

PC boards only are available from Mouser Electronics: HF amplifier board (#371-AMPPWB-2); filter PC board (#371-LPPWB-2). Price $15 each, plus shipping.

The following two kits are available from Amidon Inc (Amidon, Inc, 240 Briggs Ave, Costa Mesa, CA 92626; tel 1-800-898-1883, 714-850-4660, fax 714-850-1163): Amplifier ferrite kit (Amidon P/N HFAFC) containing the ferrite cores, balun core and magnet and Teflon wire to wind the transformers for the HF amplifier. Price: $3.50 plus shipping. Low-pass filter cores kit (Amidon P/N HFFLT) containing all iron cores and wire for the low-pass filters. Price: $4.50 plus ship.

[10]See Motorola Application Reports Q1/95, HB215, *Application Report AR346*.

Thermal runaway is a condition that occurs with bipolar transistors because bipolar transistors conduct more as temperature increases, the increased conduction causes an increase in temperature, which further increases conduction, etc. The cycle repeats until the bipolar transistor overheats and is permanently damaged.

Mike Kossor, WA2EBY, was first licensed in 1975. He earned his MSEE degree in 1987 from Stevens Institute of Technology in Hoboken, New Jersey. Mike has been employed by Lucent Technologies for 15 years, where he designs high-linearity RF amplifiers for PCS and cellular base stations. You can reach Mike at 244 N 17th St, Kenilworth, NJ 07033; **mkossor@lucent.com**.