1kW Solid State Amplifier for 144MHz Using the NXP BLF578

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This article describes a 1kW solid state FET amplifier pallet based on the NXP BLF578 LDMOS FET. The original basis for this amplifier can be referenced in the NXP application note AN10800 available on their web site. This application note describes using it for a 1kW FM broadcast amplifier.

There are 4 basic parts to the pallet; the input circuit, the output circuit, DC drain power feed and the temperature compensated bias circuit.

The Input Circuit:

The input circuit consists of a coaxial balun used to take the 50 ohm unbalanced input RF and turn it into a balanced 25 ohm source. Each side of the output of this balun will then feed a 4:1 coaxial balanced transformer system to feed the gates of the FET. The balun is made of an 11"length of 50 ohm 0.085 diameter coaxial cable. The output side then feeds through 2 DC blocking capacitors and onto the 4:1 transformer. 2 x 2.5" lengths of 18 ohm, 0.062 diameter semi rigid coaxial cable, form the transformer section. These coaxial lines are inserted each into a ferrite (Amidon BN-61-202) to increase the inductance of the outer conductor. This lowers the useable frequency of the transformer for its given length. These ferrites may not be necessary on 144MHz, but remember I was simply starting with the FM broadcast circuit. There are a few chip capacitors used for optimizing the input circuit on 144MHz. See the schematic values.

The Output Circuit:

The output circuit is essentially a duplication of the input circuit in reverse. Starting at the FET drain connections the FET feeds a 1:4 coaxial balanced transformer system. This transformer section is made with 2 x 5.25" long 25 ohm Teflon dielectric flexible coax. From the output of the transformers the RF is fed through DC blocking capacitors and into an 11" long piece of 50 ohm Teflon coax (RG142) to act as an output balun to get back to 50 ohms unbalanced. Also at the output of the transformers on the balun side of the blocking capacitors are 2 x 15pF capacitors to ground. These match the impedance between the transformer output and the balun input. At the output of the balun there is a 4.625" long stub of Teflon coax used to reduce the 3rd harmonic energy. The reason for these capacitors ifs it actually forms a matching circuit (L network) between the balun coax and the capacitors to ground.

DC Drain Power Feed:

The DC is fed to the drains of the FET through the 1:4 output transformer system. In the NXP application note the output side of the transformer system has the coax shields de-coupled to ground via a broad range of chip capacitors. My amplifier started this way. I had an “incident” while bench testing for an extended period at full output where at least one of these capacitors failed. When it did, between the DC power and the RF power available it burned the capacitors to ash and did some irreparable damage to the PC board. I did some investigation and there seems to be 2 ways of dealing with this point in this type of circuit. The first is to de-couple this point to ground with capacitors and feed this point through a choke that is again de-coupled on the DC side. The second method simply removes the capacitors that I had burned up. I thought…well I removed them but not in the neatest way, so I proceeded to operate the amplifier without them and saw essentially no operational or performance difference. This point should theoretically be RF cold anyway if (and here’s the big if) the inductance in the shield of these transformer coaxes in high enough to isolate this point from the FET drains. So the DC is fed to this point through a coil that is 5 turns of #12AWG copper wire. The DC side of this coil is bypassed with a set of capacitors forming a broadband bypass to de-couple both RF and modulation components.

The Bias Circuit:

A temperature compensated bias circuit is used and comprises the following:
An 8 V voltage regulator supplies the bias circuit. The temperature sensor (Q2) must be mounted in good thermal contact with the RF FET. The quiescent current is set using a potentiometer (R1). The RF FET gate voltage correction is approximately -4.8 mV/°C to -5.0 mV/°C.

The -2.2 mV/°C at its base is generated by Q2. This is then multiplied up by the R11 : R12 ratio for a temperature slope (i.e. approximately -15 mV/°C). The multiplication function provided by the transistor is the reason it is used rather than a diode. A portion of the -15 mV/°C is summed into the potentiometer (R1).
Resistor R4 sets the amount of temperature compensation. The ideal value proved to be 2 k Ohms. The values of R9, R13 and R14 are not important for temperature compensation. However, they are used for baseband stability and to improve IMD asymmetry at lower power levels.

Construction:

The FET will have to dissipate over 300 watts in operation. This is a small physical area to sink this amount of heat away from the part. Because of this it is a necessity to use a thick (0.5" minimum) copper heat spreader / base plate for the amplifier. Copper is a far better thermal conductor than aluminum or brass.

The PC boards are soldered to the copper spreader. They could also be screwed in place however if any oxidation forms after years of use the performance may suffer. Soldering the boards insures a good electrical bond that will last a lifetime.

As you build the amplifier I suggest building the bias circuit first. The reason for this is you can test it and know that it works properly before putting the expensive FET in place.

Once the bias circuit is finished and tested, proceed to build the input circuit next. Once that is complete then it is time to mount the FET. When mounting the FET to the heat spreader I used high performance thermal compound Arctic Silver 5. Be careful to use the correct amount. Too much or too little will not allow for proper cooling. There is plenty of information available on line at the transistor manufacturers web sites. Remember the idea is to have the compound fill any voids between the transistor flange and the heat spreader only.

Now that the FET is mounted the output circuit can be completed.

Testing:

I strongly suggest using a current limited power supply for testing and limit it to only a few amps to start with. I also suggest that the drain voltage be reduced to ~40VDC for initial testing. The combination of the current limiting and the lower drain voltage drastically increases the ruggedness of the RF FET. Under these circumstances you cant expect much power but that's

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OK. You really want to insure the amplifier has gain and appears to be working before seeing just what it'll do.

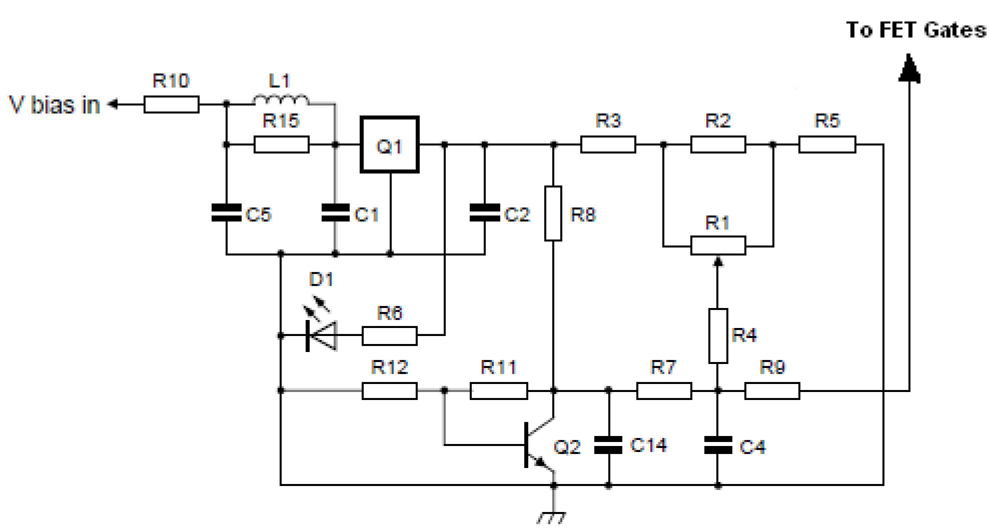
Apply the drain voltage and adjust the bias to obtain 1 amp of quiescent (idle) current.

Next apply a small amount of drive. From the results you see below 100mW of drive will make about 40 watts of output RF if things are working properly. Use the chart below as a gauge for performance. Work you way up slowly in power and drain voltage. Proceed slowly as you don't want to use the FET as a fuse. Also…Be aware of your drive source. Make sure there are no chances of power output spikes in both level and spurious frequencies. I say this because I blew a high power FET in test driving it with a small wideband amplifier from Minicircuits. The amplifier was not the problem. My source was my HP 8640B signal generator. It is absolutely fine as long as the RF is off or on. When the RF is switched from off to on it produces a spike in amplitude between 3dB and 10dB above where it is set and at a random spot in the frequency range of the generator! So I had the amplifier running at 700 watts out and switched the RF off. I turned the RF back on and the flash and sparks were just something. This amplifier now tried to make between 1.4kW and 7kW somewhere between 1 and 500MHz (who knows where). So just make sure you know what your test setup behavior.

Performance:

As shown below this amplifier exhibits about 26dB gain and can produce over 1kW of RF output power. With the coaxial stub on the output the spectral purity by itself doesn't meet the –60dBc mark required of commercial amplifiers but it is much better than what is typically seen from most 8877 type vacuum tube amplifiers without a low pass filter installed. As for linearity the 2 tone test at 1kW PEP shows 3rd order IMD at –32dB and 5th order IMD at –44dB. On the air reports from local stations on SSB have been exceptional when running at 1kW output.

Amplifier Schematics:



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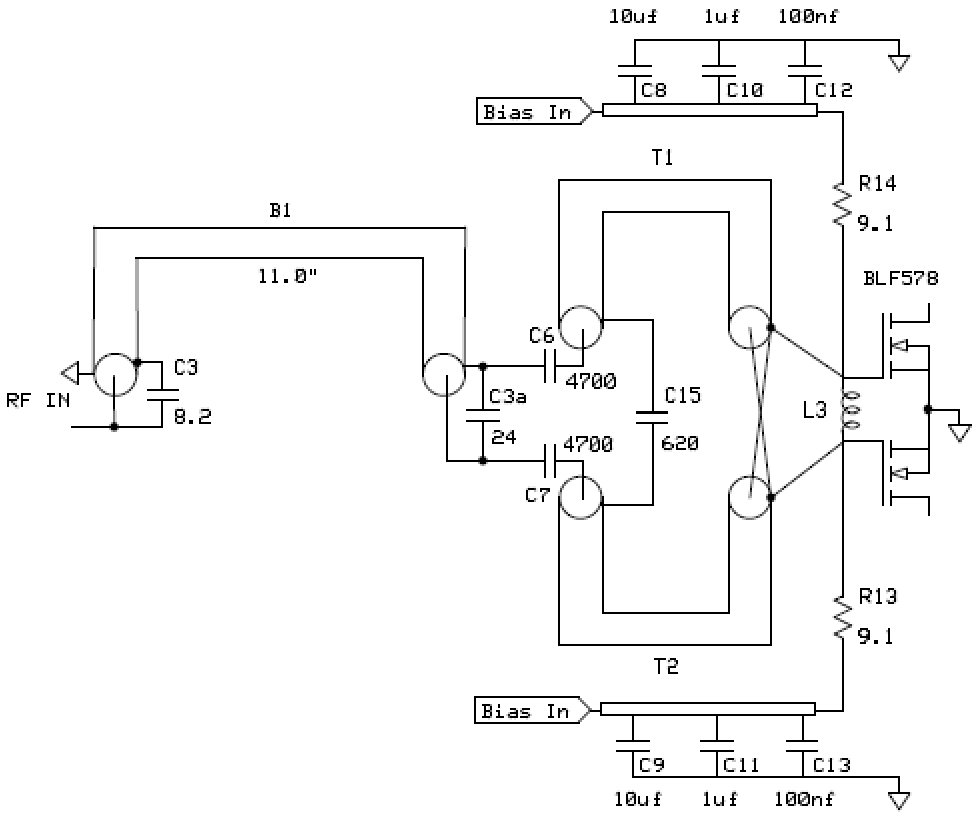

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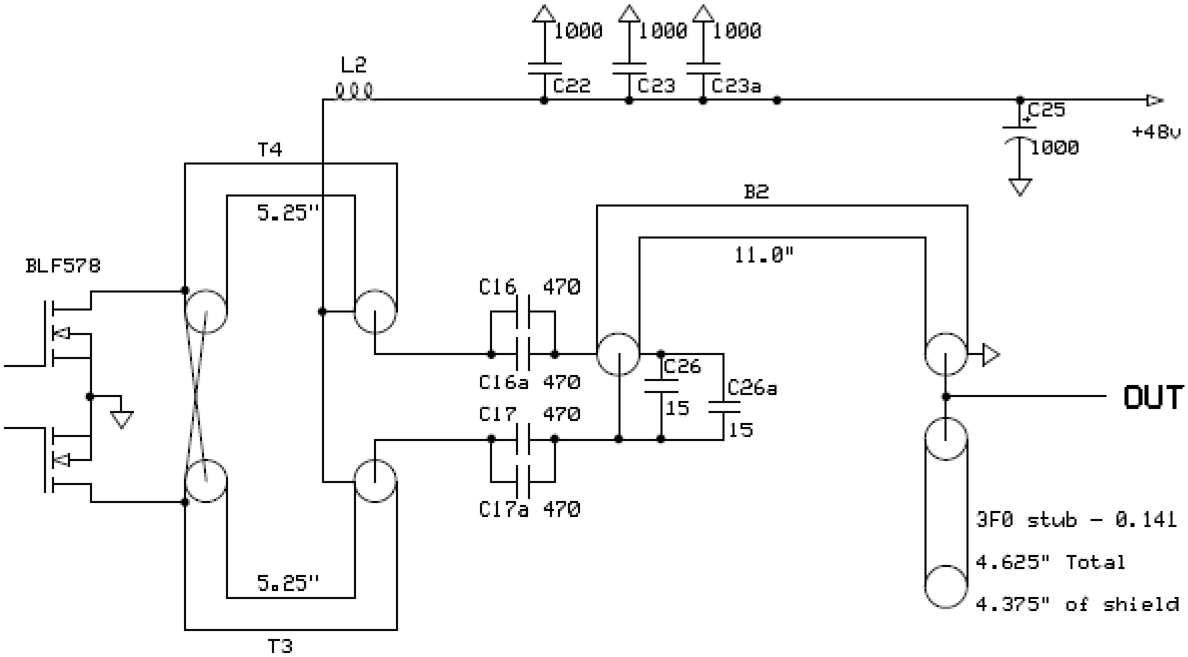
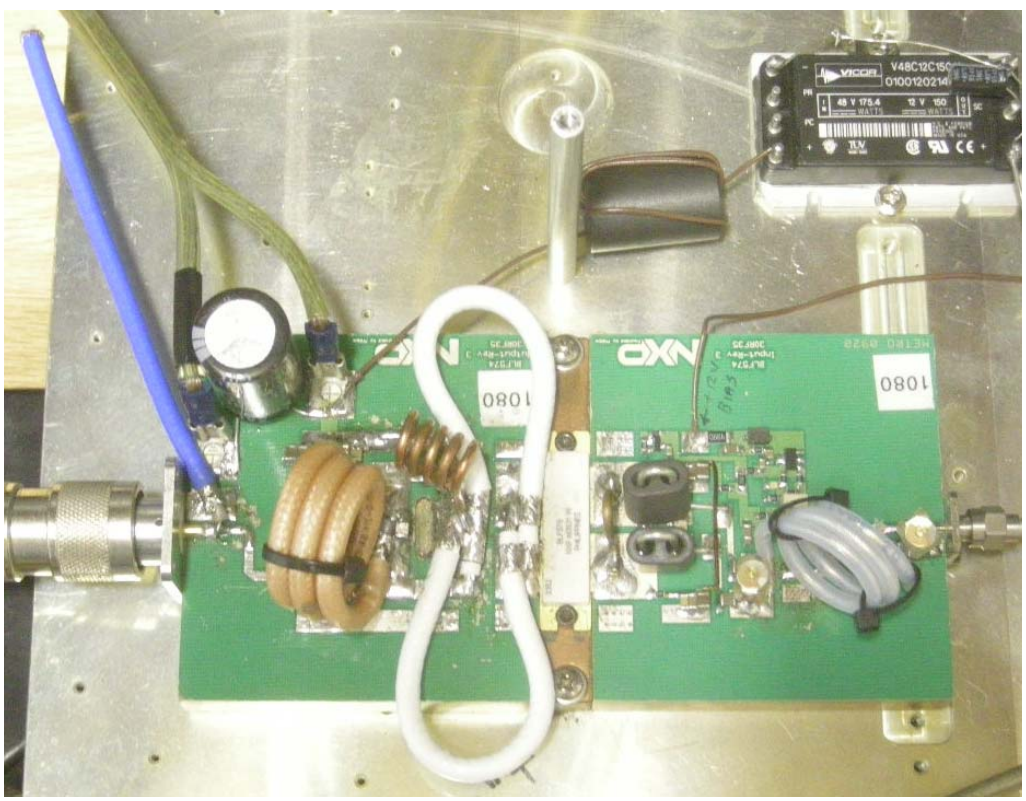


Amplifier Pictures:



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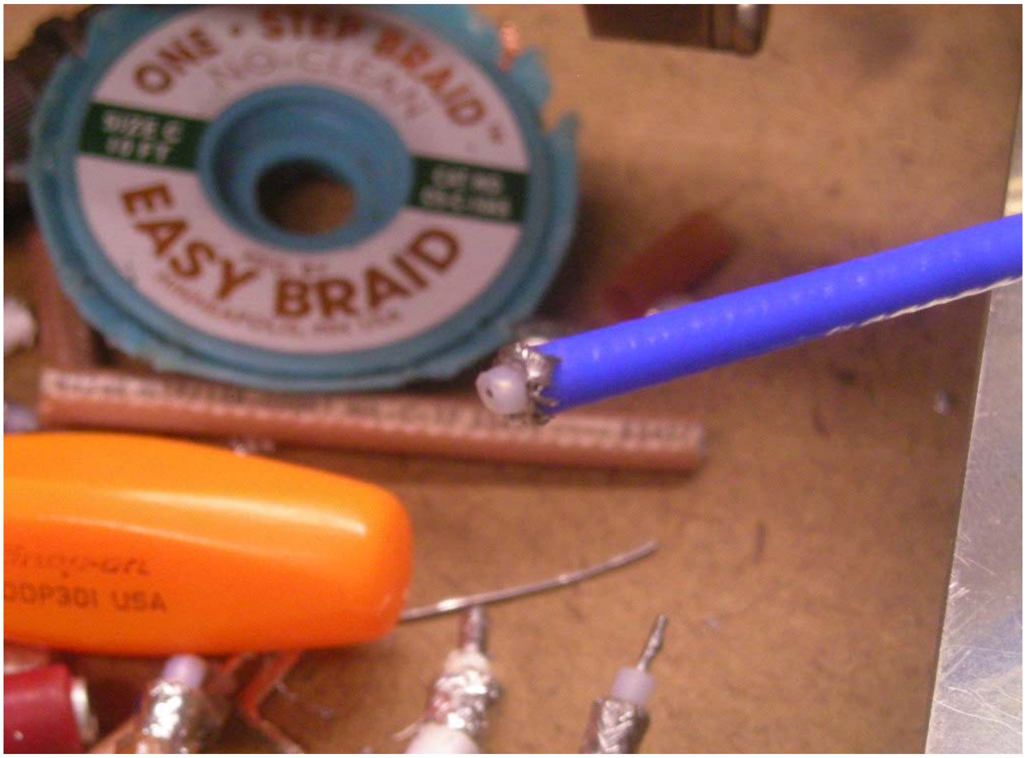

Performance Data:

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RF P in	RF P out	Gain	Compression	Vdd	Id	Dissipation	Efficiency	IMD 3	IMD 5	IMD 7
0.0	0	0	0	48	1.0	48.0	0.0%			
0.1	41	26.13	0.00	48	4.4	170.2	19.4%			
0.2	82	26.13	0.00	48	6.5	230.0	26.3%			
0.3	145	26.84	-0.71	48	8.5	263.0	35.5%			
0.4	200	26.99	-0.86	48	10.1	284.8	41.3%			
0.5	265	27.24	-1.11	48	11.6	291.8	47.6%			
0.6	300	26.99	-0.86	48	12.6	304.8	49.6%			
0.7	340	26.86	-0.74	48	13.5	308.0	52.5%			
0.8	385	26.82	-0.70	48	14.5	311.0	55.3%			
0.9	430	26.79	-0.66	48	15.5	314.0	57.8%			
1.0	470	26.72	-0.59	48	16.4	317.2	59.7%			
1.1	500	26.58	-0.45	48	16.8	306.4	62.0%			
1.2	540	26.53	-0.40	48	17.6	304.8	63.9%			
1.3	570	26.42	-0.29	48	18.3	308.4	64.9%			
1.4	600	26.32	-0.19	48	18.8	302.4	66.5%	41	43	55
1.5	635	26.27	-0.14	48	19.4	296.2	68.2%			
1.6	660	26.15	-0.03	48	19.9	295.2	69.1%			
1.7	700	26.15	-0.02	48	20.5	284.0	71.1%			
1.8	725	26.05	0.08	48	21.0	283.0	71.9%			
1.9	760	26.02	0.11	48	21.6	276.8	73.3%			
2.0	800	26.02	0.11	48	22.3	270.4	74.7%	38	44	55
2.1	820	25.92	0.21	48	22.5	260.0	75.9%			
2.2	840	25.82	0.31	48	23.0	264.0	76.1%			
2.3	860	25.73	0.40	48	23.5	268.0	76.2%			
2.4	900	25.74	0.39	48	24.2	261.6	77.5%			
2.5	930	25.71	0.42	48	24.5	246.0	79.1%			
2.6	960	25.67	0.45	48	25.0	240.0	80.0%			
2.7	980	25.60	0.53	48	25.4	239.2	80.4%			
2.8	1000	25.53	0.60	48	25.9	240.8	80.6%	32	44	52
	1200							29	52	51

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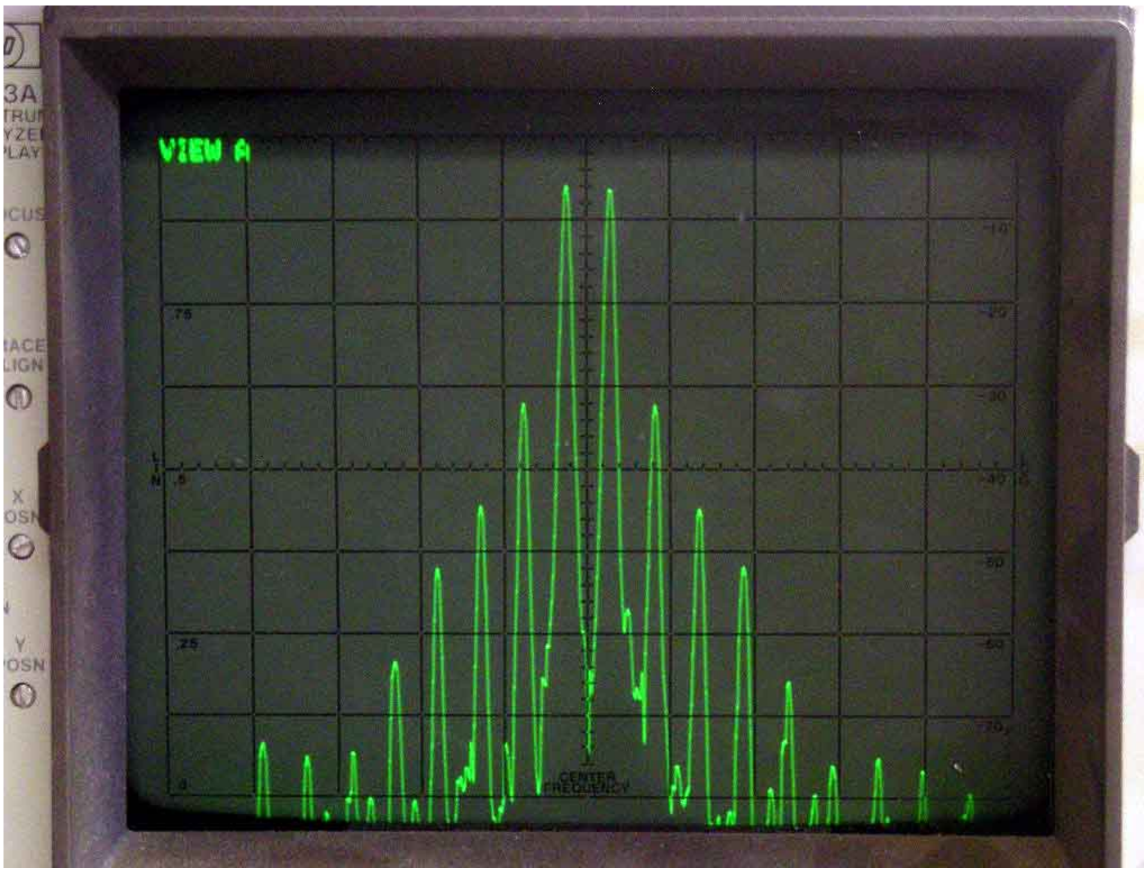
2 Tone Test 1kW PEP:
IMD3 = -32dB
IMD5 = -44dB
IMD7 = -52dB
IMD9 = -66dB



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Spectral Purity (no low pass filter):
2f0 = -49dBc
3f0 = -44dBc
4f0 = -60dBc
5f0 = -58dBc