QEX 92

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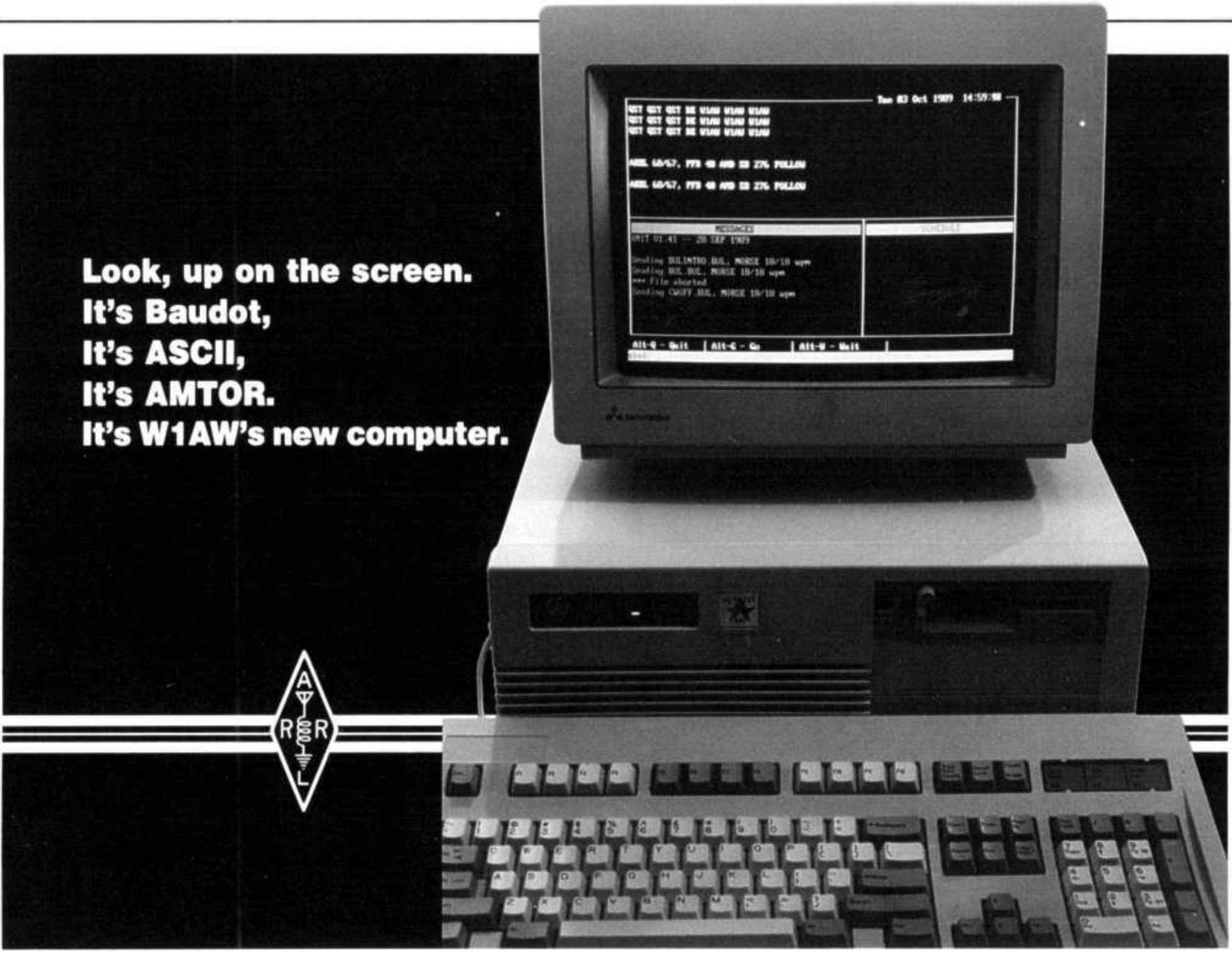
ARRL Experimenters' Exchange

OCTOBER 1989



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2) document advanced technical work in the Amateur Radio field
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Empirically Speaking. . .

Teaching A New Dog Old Tricks

Heard W1AW lately? The bulletin and code practice transmissions are coming from an entirely new transmitting system. We thought you might be interested in one aspect of that system: the control computer. In the just-retired W1AW system, Morse and data keying signals were generated by a Heath H89 computer. This Z80-microprocessor-based computer ran a program written especially for W1AW by Robert Anderson, K2BJG. When we were designing the new system, we knew we wanted to keep the same functionality as the H89s provided, but we needed new machines. The H89s were reaching the end of their useful lifetime, as years of all-day operation were taking their toll. Our solution was to specify IBM® PC/AT type systems as the new control computers. We felt that such computers would serve the immediate need as well as provide a growth path: We could add more control functions to the computer's duties when needed.

There was just one problem with this approach. Because there are periodic and aperiodic interrupts occurring in the PC/AT, we couldn't use software loops to perform the timing of the outgoing data. Hardware was needed to clock the data out in a steady, jitterless stream. A number of possibilities were considered, and finally we decided to use a PC⋆Packet Adapter from DRSI. This board contains a Zilog 8530 serial communication controller chip. This chip can output asynchronous (RTTY) and synchronous data as well as packet. (We aren't even presently using the packet capability!) The asynchronous mode is used when transmitting ASCII and Baudot RTTY signals, while the synchronous mode is used for Morse and AMTOR FEC transmissions. As used in the W1AW software, the synchronous mode simply accepts 8-bit chunks of data from the CPU and sends the bits out serially, *without* start or stop bits. It can be used to send any stream of data by just loading it with the right sequence of bits.

During program design, we grappled with the problem of Farnsworth timing. Simply put, Farnsworth timing is the sending of Morse using a character speed faster than the overall speed. For example, when W1AW is sending Morse at 13 WPM, it sends the characters at 18 WPM. That's a simple enough idea, but exactly how much time should be inserted between the end of one character and the beginning of the next? Before any code could be written, we had to derive equations to express the timing constants.

One requirement of the program was to allow automatic daily scheduling. This lets the operator set up the computer with a list of files to transmit, along with the time, mode and speed of the transmission for an entire day. The computer automatically activates the transmitters and, after a short delay, sends the data. Once the operator has set the mode and frequency of the radios, the computer takes it from there. (We may eventually add control of the radios to the system as well.) While the data is being transmitted it is displayed on the computer screen.

If you get a chance to visit W1AW during bulletin transmissions, ask to take a look at the control computer. It's one of the elements of a complete, state-of-the-art amateur station: W1AW.—*KE3Z*

Wideband Microwave Amplifier Design

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How High the Moon/How Wide the Band?

High frequency is a relative thing. Take the HF ham bands. (Please!) The only thing "High Frequency" about them to most microwavers is that they're fine for coordinating scheds (we've all heard our friends on 3818 kHz saying "I'm gonna send Os now"), and they make dandy IFs for *real* RF converters. True hams (and if you're reading this, that's you) long for the more exotic frequencies up the spectrum.

But one person's exotic is another's mundane. About fifteen years ago I applied for a position as a microwave receiver designer at a well-known aerospace company. I had recently developed and published a number of preamp, filter and mixer designs for the 23-cm amateur band, and thinking myself quite the microwave engineer, brought some manuscripts and prototypes along to the interview. "Interesting," was the manager's comment, and he hired me to work in the IF Amplifier Section.

Ah, but what IF amplifiers they were! This company was converting wide expanses of the millimeter waves down to the "lower spectrum" below 10 GHz! An early task to which I was assigned was the design of a 2- to 6-GHz amplifier with flat gain and noise figure. A challenge to be sure, as we hams seldom think in terms of true wideband performance. Our widest microwave bands are scarcely ten percent from end-to-end, and here I had to span an octave and a half. It turns out the project was a challenge to the professionals as well; before the amplifier was completed, a dozen engineers ended up occupying two large mainframe computers for the better part of a year. Broadbanding microwave circuitry, it seems, is no trivial task.

Why so Narrow?

Solid-state microwave active devices tend to be frequency selective by nature. Consider the scattering parameters of the familiar MRF-901 silicon bipolar junction transistor, as seen in Table 1. Note that the magnitude of S_{21}, forward voltage transmission coefficient, diminishes predictably with frequency. Each time frequency doubles, this figure for unmatched forward voltage gain drops in half.

If we expressed gain logarithmically, we'd see that gain is rolling off at roughly six dB per octave—exactly the performance we'd expect from a monotonic (one-pole) low pass filter beyond cutoff. Field-effect transistors are no different in this respect, as Table 2 indicates. Even MMICs, often used as uniform gain blocks, have a pronounced gain roll-off with increasing frequency (see Table 3). Which leaves us with the conclusion that all microwave active devices are inherently low-pass, and will resist producing uniform gain across a wide band of frequencies.

Table 1

Scattering parameters for a typical microwave silicon bipolar junction transistor, the Motorola MRF-901, biased at 5 volts V_{ce} and 5 mA I_c. Note that beyond about 200 MHz, S_{21} decreases quite uniformly with frequency (see text).

	S_{11}		S_{21}		S_{12}		S_{22}	
FREQ	MAGN	ANG	MAGN	ANG	MAGN	ANG	MAGN	ANG
100	0.71	-38	11.3	153	0.03	68	0.92	-17
200	0.62	-75	9.48	133	0.05	55	0.76	-29
500	0.54	-141	5.4	100	0.07	43	0.48	-44
1000	0.53	178	2.93	76	0.09	48	0.40	-56
2000	0.59	130	1.51	48	0.16	62	0.35	-85

Table 2

Scattering parameters for a typical microwave gallium arsenide field effect transistor, the Avantek ATF10235 biased at 2 volts V_{ds} and 20 mA I_d. Note that beyond about 4 GHz, S_{21} decreases quite uniformly with frequency (see text).

	S_{11}		S_{21}		S_{12}		S_{22}	
FREQ	MAGN	ANG	MAGN	ANG	MAGN	ANG	MAGN	ANG
500	0.97	-20	5.68	162	0.023	76	0.47	-11
1000	0.93	-41	5.58	143	0.050	71	0.45	-23
2000	0.77	-81	4.76	107	0.086	51	0.36	-38
3000	0.59	-114	4.06	80	0.120	35	0.30	-51
4000	0.48	-148	3.51	52	0.149	18	0.23	-67
5000	0.46	166	3.03	26	0.172	3	0.10	-67
6000	0.53	125	2.65	1	0.189	-14	0.09	48
7000	0.62	96	2.22	-20	0.191	-28	0.24	55
8000	0.71	73	1.75	-39	0.189	-41	0.37	51
9000	0.75	54	1.47	-55	0.184	-46	0.46	42
10000	0.78	39	1.28	-72	0.180	-59	0.51	34
11000	0.82	26	1.04	-86	0.179	-71	0.54	26
12000	0.84	12	0.95	-101	0.177	-82	0.54	17

Fortunately, as can be seen in Tables 1 through 3, the input and output reflection coefficients (S_{11} and S_{22}) of most microwave active devices are somewhat greater than zero, which means there's more gain to be had at the higher frequencies, by matching the input and output to the system impedance (typically 50 ohms). Of course, matching the transistor, MMIC or FET at the *higher* frequencies (where gain is lowest) will tend to increase gain at those frequencies, while leaving the device mismatched at the *lowest* frequencies (where there's likely already too much gain) will tend to reduce amplifier gain in that region. Thus a technique widely utilized to obtain wideband performance from microwave transistors is *frequency selective matching*.

In optimizing performance of that commercial 2- to 6-GHz IF amplifier of long ago, my colleagues and I developed a seven step procedure for wideband amplifier design. It's still valid today, and is illustrated here, over that same range of frequencies, in the design of an amplifier using more contemporary active devices and software tools. But before we

Table 3

Scattering parameters for a typical silicon monolithic microwave integrated circuit, the Avantek MSA0835, biased at 8 volts V_c and 36 mA I_c. Note that, even for these supposedly constant gain devices, S_{21} decreases quite uniformly with frequency (see text).

	S_{11}		S_{21}		S_{12}		S_{22}	
FREQ	MAGN	ANG	MAGN	ANG	MAGN	ANG	MAGN	ANG
100	0.63	-17	42.02	161	0.013	55	0.63	-19
200	0.58	-33	37.52	145	0.021	47	0.56	-37
400	0.49	-56	28.50	119	0.033	54	0.42	-66
600	0.40	-70	21.54	103	0.040	55	0.32	-84
800	0.35	-80	17.01	92	0.050	53	0.24	-98
1000	0.33	-89	13.98	82	0.057	52	0.18	-107
1500	0.30	-111	9.45	64	0.079	51	0.09	-126
2000	0.30	-133	7.03	48	0.098	44	0.07	-141
2500	0.32	-150	5.53	39	0.110	42	0.06	-166
3000	0.34	-170	4.56	26	0.122	36	0.06	-106
3500	0.38	175	3.86	14	0.133	32	0.08	-100
4000	0.39	162	3.33	2	0.146	27	0.12	-101
5000	0.42	132	2.47	-21	0.165	19	0.21	-113
6000	0.52	95	1.94	-45	0.187	7	0.20	-149

begin, some thoughts about software and technique are in order.

Disclaimer

There are at least as many techniques for broadbanding microwave amplifiers as there are broadband microwave amplifiers! One common approach involves frequency-selective negative feedback, where the signal at the collector of a common-emitter bipolar stage is fed back to the base through an inductor or other low-pass circuit. This provides a degenerative feedback path at low frequencies, but not higher, and tends to level the gain of the amplifier across the band.

Another popular trick involves selective emitter swamping. Here a bypass capacitor across an emitter-bias resistor is chosen so as to short the resistor at high frequencies (maximizing gain) but not lower in the band. The result is a certain amount of gain leveling through emitter degeneration.

In the amplifier presented here, I achieve wideband performance through frequency selective matching. I make no claims of superiority for this method; I merely maintain that it works for me. If you have another technique which you favor, please write it up for *QEX*!

Choose Your Tools Carefully!

Today we're blessed with a wide variety of software tools to facilitate microwave circuit design and analysis. One of my favorites is a BASIC program for s-parameter design developed by Vatt[1], and since modified by myself and others, to the point that its own mother wouldn't recognize it. Unfortunately, like many of my published procedures[2,3,4], programs written to run on "low-end" machines perform analysis at a single frequency only. That's an acceptable compromise for the typical narrow-band ham application, but just isn't good enough when contemplating wideband design.

To illustrate why, let's evaluate the scattering parameters for a favorite MMIC at its highest characterized frequency, 6 GHz. The numbers are in Table 3. We'll evaluate them using the Scalar Approximation technique which I presented previously[5]. Note that at 6 GHz, the forward voltage transmission coefficient (S_{21}) has a magnitude of 1.94, which translates to 5.76 dB of unilateral transducer gain G_{tu}. The input voltage reflection coefficient (S_{11}) magnitude is 0.52, which equates to an input mismatch loss of 1.269 dB, and the corresponding numbers for the output (S_{22}) are 0.20 and 0.177 dB, respectively. Adding mismatch losses to transducer gain, we see that the approximate Maximum Available Gain (MAG) from this device at 6 GHz is on the order of 7.4 dB.

Vatt's fine BASIC program, as modified, yields more accurate results than the Scalar Approximation. MAG is really a dB and a half higher than we estimated above, which suggests this device has the potential to make a usable 6-GHz amplifier. Matching stubs are dimensioned for 1/16-inch fiberglass-epoxy printed circuit board (not really the best choice of materials at 6 GHz), as seen in Table 4. The most useful values, open stub wavelength and placement, are highlighted.

Now let's port these wavelengths and s-parameters over to a full-blown swept-frequency microwave circuit analysis program. I use SuperStar[6], although if you're fortunate enough to have access to SuperCompact[7] or Touchstone[8] you'll get similar results. To build the required circuit file (Table 5) it was necessary to multiply the wavelength dimensions from Fig 4 by 360, as most such software inputs transmission-line lengths in degrees at a specified frequency.

SuperStar swept-frequency analysis of the above circuit file (Fig 1) confirms that we have indeed optimized the MMIC at 6 GHz. Note that the high-frequency (clockwise) ends of the S_{11} and S_{22} arcs

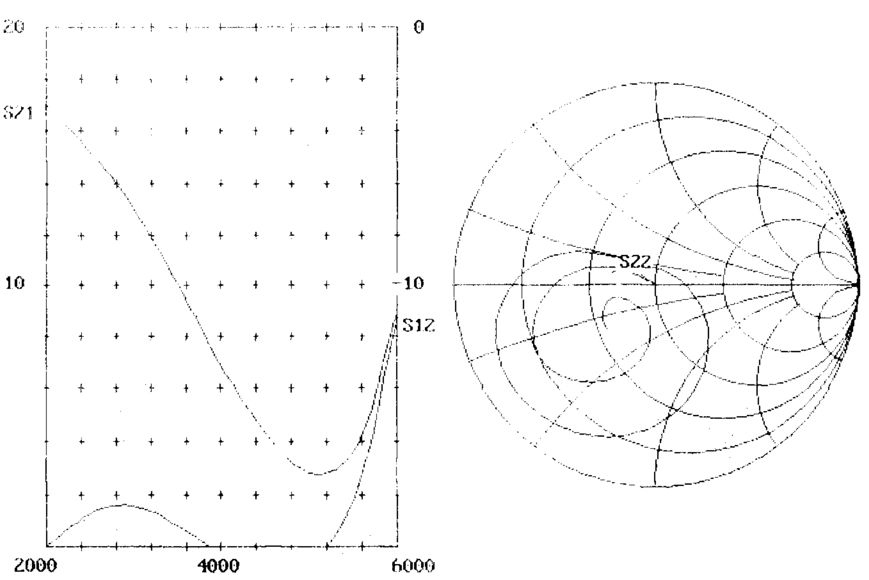

Fig 1—A perfect match at the high-frequency end yields some rather strange swept-frequency results (see text).

---

[1]Notes appear on page 13.

Table 4

Single-frequency (6 GHz) s-parameter analysis for the MSA0835 MMIC yields a rudimentary amplifier design.

```
SMALL-SIGNAL AMPLIFIER DESIGN BY MICROCOMM
         TRANSISTOR PARAMETERS:
S11          =  0.520 /   95.0 Deg
S12          =  0.187 /    7.0 Deg
S21          =  1.940 /  -45.0 Deg
S22          =  0.200 / -149.0 Deg
Zo           =                50.0 Ohms

K            = + 1.046764
Gtu          =  5.76          dB
MAG          =  8.84          dB
MSG          = 10.16          dB
GAMMA ms     =  0.822 / -97.0 Deg
GAMMA ml     =  0.717 / 140.0 Deg
INPUT VSWR   =  1.00
OUTPUT VSWR =  1.00

INPUT & OUTPUT WILL BE MATCHED USING  50-Ohm MICROSTRIP
                        ==SERIES=LINE=======>
                      |/               S
  >======SERIES=LINE==|                T
       S              |\               U
       T                |              B
       U                |
       B                |
                        |
  >-----------------------------------------> 
CENTER FREQUENCY OF AMPLIFIER =  6000  MHz
DESIGNED FOR  4.8  DIELECTRIC CONSTANT,
.059 IN. THICK SUBSTRATE

NOMINAL LINE WIDTH IS .109 IN. [2.8 mm]

INPUT NETWORK
  USING A SHORTED STUB:
    STUB WAVELENGTH = .053       LENGTH =  0.055 IN. [   1.4 mm]
    SERIES WAVELENGTH = .337     LENGTH =  0.346 IN. [   8.8 mm]
  USING AN OPEN STUB:
    STUB WAVELENGTH = .197       LENGTH =  0.203 IN. [   5.2 mm]
    STUB EQUIV SHUNT CAP. =  1.5 pF
    SERIES WAVELENGTH = .433     LENGTH =  0.446 IN. [ 11.3 mm]

OUTPUT NETWORK
  USING A SHORTED STUB:
    STUB WAVELENGTH = .072       LENGTH =  0.074 IN. [   1.9 mm]
    SERIES WAVELENGTH = .494     LENGTH =  0.509 IN. [ 12.9 mm]
  USING AN OPEN STUB:
    STUB WAVELENGTH = .178       LENGTH =  0.183 IN. [   4.7 mm]
    STUB EQUIV SHUNT CAP. =  1.1 pF
    SERIES WAVELENGTH = .117     LENGTH =  0.120 IN. [   3.1 mm]
```

Table 5

SuperStar circuit file for testing the single-frequency matching stub design, developed per Vatt (Ref 1).

```
This file is : 2-6ghz.amp

circuit 2-6ghz.amp
ost aa dg 50 ?70.9      6000
trl bb dg 50 ?155.9     6000
two cc sp 50 '\circuits\star\data\msa0835.836
trl dd dg 50 ?42        6000
ost ee dg 50 ?64        6000
cax aa ee
output
gph aa s21 50 0 20
gph aa s12 50 -20 0
smh aa s11 50
smh aa s22 50
freq
swp 2000 6000 21
```

are right in the middle of the Smith Chart, and the swept gain (S_{21}) really coincides with our calculated MAG at 6 GHz. But notice that simply matching the device at the highest operating frequency has failed to provide uniform gain across the operating band. In fact, a pronounced null at 5.1 GHz makes this a less than ideal broadband amplifier. Our actual design procedure is going to have to be quite a bit more interactive, and will of course require either swept-frequency-analysis software, or one heck of a lot of breadboarding.

STEP 1: Characterize the Active Device

It's always a good idea to characterize the selected active device, before expending any effort in circuit design. The S-parameters listed in Table 3 are typed into an ASCII data file, which is accessed by the SuperStar analysis software in the circuit file shown at the top of Table 6. The program produces a listing of input and output VSWR, forward and reverse gain, and Rollett's Stability Factor (K), over the selected frequency range, as seen in Table 6. These data, which represent the transducer performance of the active device (and can be similarly found for bipolar junction transistors and FETs), are shown graphically in Fig 2. Note that the forward gain drops from more than 16 dB at the low end of the band, to under 6 dB at the top frequency. Note also that the input match (S_{11}) is fair across the band, and the output match (S_{22}) is excellent, as seen by its proximity to the middle of the Smith Chart.

But gain and match tell only half the story. Will this device yield a stable amplifier, or will it perhaps oscillate? We have several clues in the Data Table. Note that, at least at the lower operating frequencies, the reverse loss (S_{21}) is a scant 3 dB more than the forward gain. Further, stability factor K is less than unity. Stability Circle analysis (Figs 3 and 4) shows regions of the Smith Chart which are cut by the stability circles, which further suggests that the device is only conditionally stable. Unless we take some very deliberate steps to prevent oscillation, we may find this amplifier generating signals of its own.

STEP 2: Swamp the Output for Stability

One time-honored technique for improving the stability of only marginally stable devices is resistive swamping. A resistance of carefully chosen value is applied in shunt with either the input or output terminals of the device. The result is to reduce the available gain of the device to just below the threshold of potential instability. Of course, any resistive swamping of a transistor's input will degrade noise figure, thus is to be avoided in receive applications. Similarly, resistive

Table 6

Circuit file (top) and analysis results (bottom) show characteristics of the selected MMIC over the entire 2-6 GHz frequency range.

```
This file is : 2-6ghz.amp


circuit 2-6ghz.amp
two aa sp 50 '\circuits\star\data\msa0835.836
output
gph aa s21 50 0 20
gph aa s12 50 -20 0
smh aa s11 50
smh aa s22 50
freq
swp 2000 6000 21

Run of 2-6ghz.amp  === SuperStar ===    Wed Aug 31 03:27:03 1988

FREQ(MHz) INPUT VSWR   S21 dB< ANG      S12 dB   OUTPUT VSWR      K

 2000.00     1.857     16.939< 48.000    -20.175     1.151      0.9807838
 2200.00     1.877     16.140< 44.906    -19.761     1.138      0.9961811
 2400.00     1.915     15.294< 41.167    -19.365     1.130      1.014019
 2600.00     1.944     14.513< 36.789    -18.993     1.116      1.031817
 2800.00     1.973     13.833< 31.809    -18.633     1.110      1.04432
 3000.00     2.030     13.179< 26.000    -18.273     1.128      1.05125
 3200.00     2.091     12.585< 21.677    -17.970     1.146      1.057031
 3400.00     2.175     12.008< 16.728    -17.671     1.164      1.058996
 3600.00     2.228     11.462< 11.879    -17.360     1.193      1.06115
 3800.00     2.245     10.938< 7.2282    -17.036     1.232      1.064469
 4000.00     2.279     10.449< 2.0000    -16.713     1.273      1.062847
 4200.00     2.253     9.8962<-1.5416    -16.504     1.318      1.080762
 4400.00     2.251     9.3462<-5.5633    -16.293     1.367      1.095185
 4600.00     2.273     8.8108<-10.121    -16.080     1.419      1.104496
 4800.00     2.319     8.3065<-15.260    -15.865     1.474      1.106595
 5000.00     2.390     7.8539<-21.000    -15.650     1.532      1.098996
 5200.00     2.423     7.3687<-24.874    -15.455     1.505      1.121526
 5400.00     2.513     6.9017<-29.198    -15.246     1.489      1.13011
 5600.00     2.662     6.4662<-33.996    -15.026     1.482      1.122171
 5800.00     2.876     6.0784<-39.272    -14.798     1.486      1.095112
 6000.00     3.167     5.7560<-45.000    -14.563     1.500      1.046764
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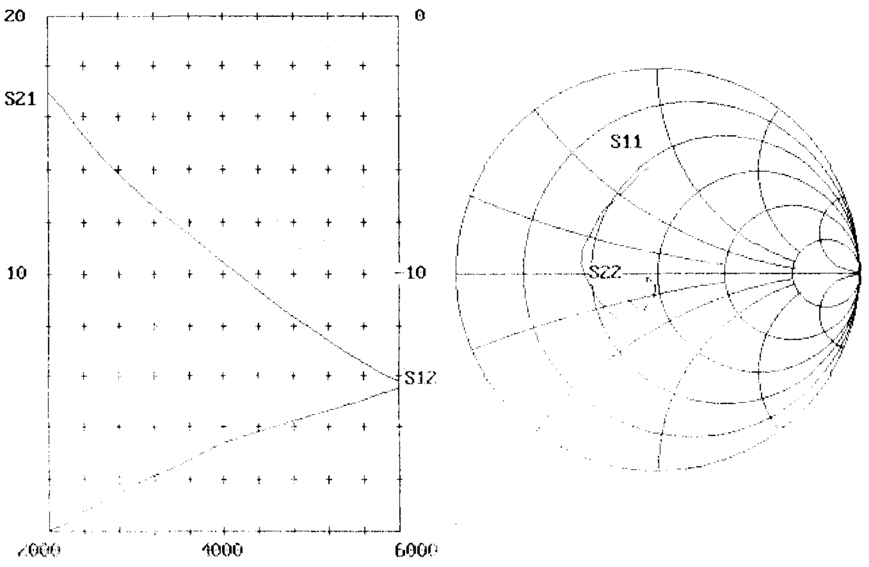
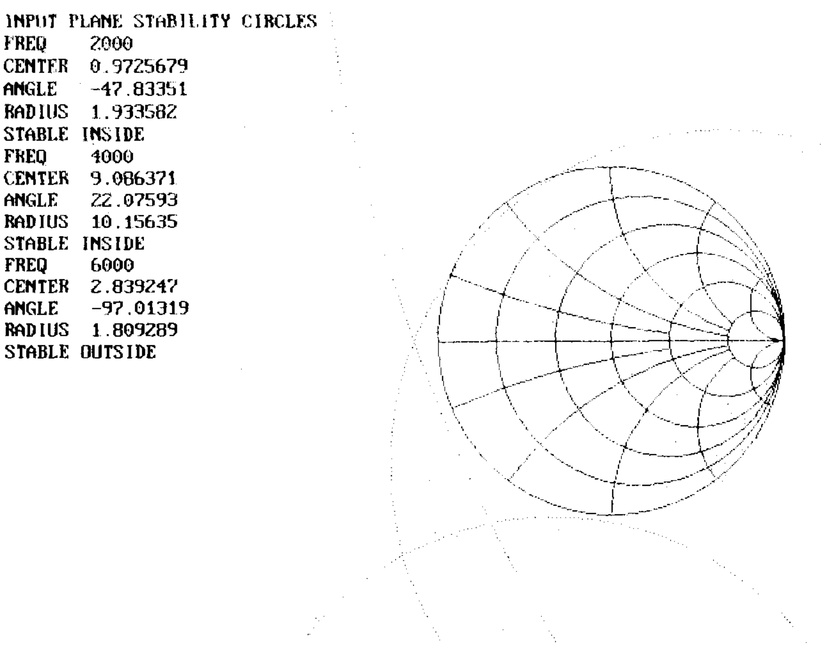


Fig 2—Transducer swept performance of the selected MMIC.

swamping at a transistor's output degrades output power, and is thus to be avoided in transmit applications. The decision of whether to place the swamping resistor at the input or output of the active device is highly application dependent.

The example circuit was originally intended to be utilized as an IF amplifier in a millimeter-wave receiver, hence output swamping was selected. A 100-ohm resistor (in fact, part of the collector bias resistance) was selected, and added to the circuit file for computer analysis, as seen in Table 7. The resulting gain dropped more than one and a half dB, which nudged the Rollet Stability factor above unity across the entire 2- to 6-GHz band. Note that input and output VSWR were slightly degraded in the process. In the words of that old Greek philosopher, Will Rogers, there ain't no free lunch.

Fig 5 shows graphically that gain and match are indeed degraded with resistive swamping. However, Input (Fig 6) and



```
INPUT PLANE STABILITY CIRCLES
FREQ    2000
CENTER  0.9725679
ANGLE   -47.83351
RADIUS  1.933582
STABLE INSIDE
FREQ    4000
CENTER  9.086371
ANGLE   22.07593
RADIUS  10.15635
STABLE INSIDE
FREQ    6000
CENTER  2.839247
ANGLE   -97.01319
RADIUS  1.809289
STABLE OUTSIDE
```

Fig 3—Input stability circles for the naked MMIC indicate regions of potential oscillation (see text).

Output (Fig 7) Stability Circles confirm that the device is now unconditionally stable over the entire operating frequency range.

STEP 3: Match the Input at the Highest Frequency

S-parameter analysis shows the input of the MMIC/swamping resistor cascade to be somewhat inductive at the higher frequencies; thus, a small amount of capacitance in the form of an open-circuited stub will be applied in shunt with the input terminal. The length of the stub is varied empirically (Table 8) for a reasonable input match at the top of the band. This results in increased high-frequency gain, along with slightly degraded gain and match at the lower frequencies, as seen in Fig 8.

Note the input match (S_{11}) curve in Fig 8, which rotates clockwise about the Smith chart with increasing frequency (as do all reflection coefficient curves). The objective in matching the input is to end up with the curve roughly circling the middle of the chart, with a minimum radius. It should also be noted that the matching stub for the swamped MMIC

Table 7

Results of adding a swamping resistor across the output terminals of the MMIC. The device is now unconditionally stable across the band.

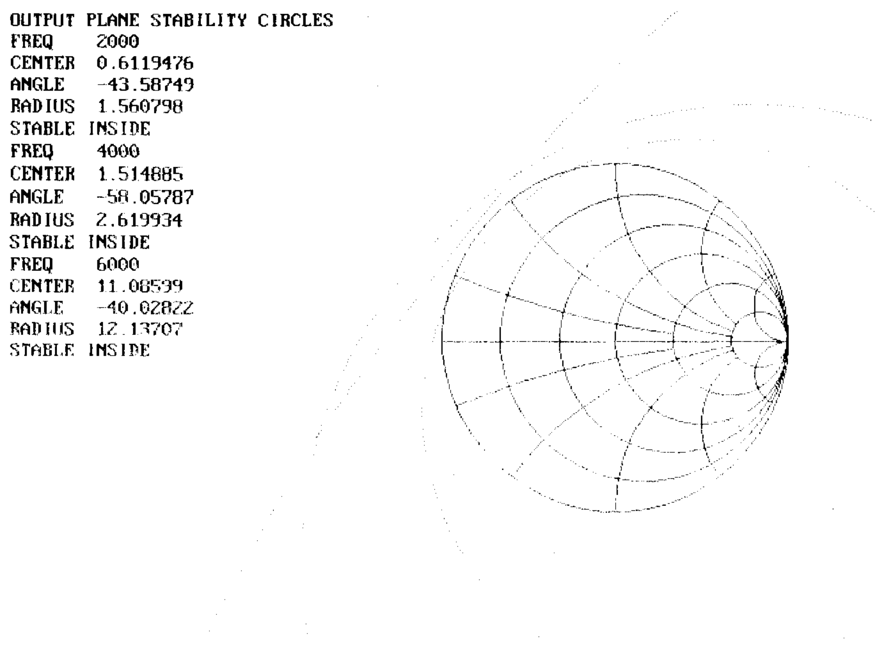
```
This file is : 2-6ghz.amp

circuit 2-6ghz.amp
two aa sp 50 '\circuits\star\data\msa0835.836
res bb pa ?100
cax aa bb
output
gph aa s21 50 0 20
gph aa s12 50 -20 0
smh aa s11 50
smh aa s22 50
freq
swp 2000 6000 21

Run of 2-6ghz.amp   === SuperStar ===    Wed Aug 31 03:30:12 1988

FREQ(MHz) INPUT VSWR   S21 dB< ANG      S12 dB    OUTPUT VSWR      K

 2000.00     2.389    15.096< 48.510   -22.019     1.620       1.008833
 2200.00     2.364    14.299< 45.280   -21.602     1.621       1.04607
 2400.00     2.368    13.456< 41.404   -21.202     1.623       1.085668
 2600.00     2.369    12.661< 37.056   -20.844     1.606       1.130241
 2800.00     2.377    11.953< 32.275   -20.513     1.573       1.172316
 3000.00     2.432    11.269< 26.663   -20.183     1.543       1.202683
 3200.00     2.488    10.673< 22.437   -19.882     1.543       1.221843
 3400.00     2.581    10.094< 17.584   -19.585     1.544       1.231237
 3600.00     2.642    9.5499< 12.875   -19.273     1.552       1.239554
 3800.00     2.662    9.0316< 8.4036   -18.942     1.568       1.250228
 4000.00     2.709    8.5481< 3.3558   -18.614     1.584       1.25047
 4200.00     2.651    8.0154<-.00839   -18.385     1.619       1.290602
 4400.00     2.627    7.4854<-3.8519   -18.154     1.655       1.323193
 4600.00     2.637    6.9700<-8.2309   -17.921     1.693       1.345431
 4800.00     2.684    6.4855<-13.190   -17.686     1.733       1.353742
 5000.00     2.768    6.0528<-18.749   -17.452     1.775       1.343959
 5200.00     2.783    5.6003<-22.826   -17.223     1.801       1.366322
 5400.00     2.872    5.1661<-27.354   -16.981     1.830       1.364209
 5600.00     3.042    4.7635<-32.358   -16.729     1.864       1.334229
 5800.00     3.304    4.4084<-37.841   -16.468     1.901       1.273276
 6000.00     3.682    4.1189<-43.778   -16.200     1.941       1.179243
```



```
OUTPUT PLANE STABILITY CIRCLES
FREQ    2000
CENTER  0.6119476
ANGLE   -43.58749
RADIUS  1.560798
STABLE INSIDE
FREQ    4000
CENTER  1.514885
ANGLE   -58.05787
RADIUS  2.619934
STABLE INSIDE
FREQ    6000
CENTER  11.08599
ANGLE   -40.02822
RADIUS  12.13707
STABLE INSIDE
```

Fig 4—Output stability circles for the MMIC as a transducer further suggest that this device is not unconditionally stable.

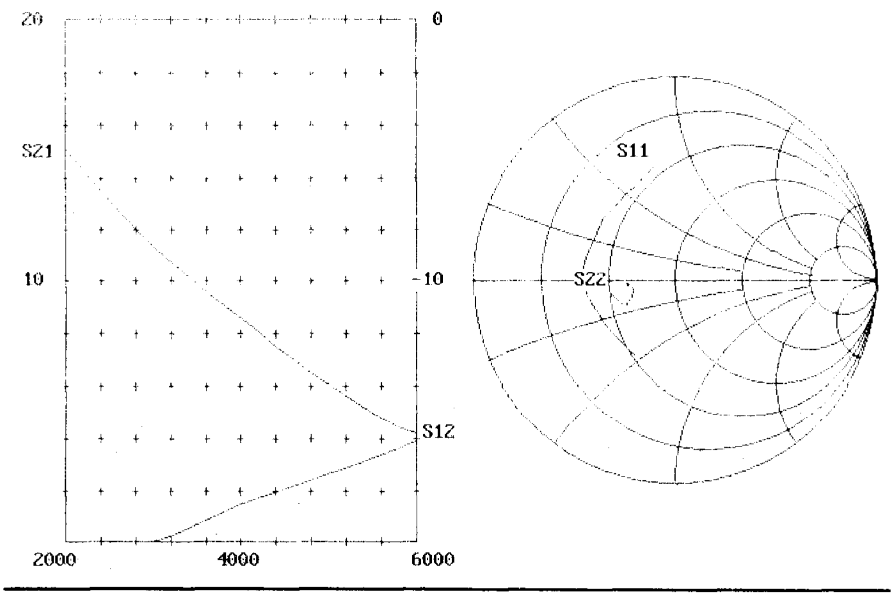


Fig 5—Transducer swept response for the swamped MMIC. Compared to Fig 2, gain is reduced, match is degraded.

bears scant resemblance to the stub which was applied to the MMIC alone, as in Table 6. This is because the transducer characteristics with and without swamping differ considerably, as seen by comparing Figs 2 and 5.

STEP 4: Match the Output at the Highest Frequency

The S_{22} arc in Fig 8 falls very near to the real (nonreactive) axis, somewhat to the left of the Smith chart's center. One easy way to match the output is to rotate this impedance clockwise one-quarter of the way around the chart, by means of a series microstripline 45 degrees long at the highest operating frequency. This will result in an inductive complex impedance which can be resonated by an open stub, in a manner similar to the input matching circuit.

As seen in Table 9, optimizing the output stub length and placement results in a further gain increase at the high frequencies, a considerable improvement in output VSWR, and a slight degradation in input match due to the S_{12}-related feedback through the active device.

STEP 5: Diddle and Tweak

Every engineer or technician is likely to develop his or her own tweak and peak technique, but all will recognize that input and output tuning are somewhat interactive. This is due to the feedback path between the output and input of any active device, as evidenced by the nonzero Reverse Voltage Transmission Coefficient, S_{12}. While fine-tuning the stub values, it is useful to be able to view swept gain and match simultaneously. The better microwave circuit analysis software (References 6 through 8) facilitates on-screen tweaking of the sort which actual circuits give you on an automatic network analyzer. Fig 9 shows the performance I achieved by tweaking the length and position of the input and output matching stubs for the 2- to 6-GHz amplifier.

Most advanced circuit analysis programs contain an "optimization" algorithm, in which the user sets target values for key parameters, along with priorities, and identifies component values to be tweaked. To tell the truth, I hardly use them, preferring the manual tuning procedure. Anyone with even passing experience in manually tuning microwave circuits on the bench will have developed an intuition for which way to go on which trimmer to accomplish a given objective. I would suggest that the computer between your ears is still more efficient than the one on your desk, in determining an appropriate trade-off between conflicting requirements.

STEP 6: Mismatch the Input at the Lowest Frequency

You will notice in Fig 9 that the low frequency gain is still considerably higher than that achieved higher in the band. We have already raised the high-end gain as far as the s-parameters will allow; if flat response is desired, we're going to have to lower the gain at the bottom of the band. The easiest way to do so is to add a high-pass filter into the circuit, and this is readily accomplished with series capacitance. Since we're going to need dc-blocking capacitors at the input and output of the transistor or MMIC to keep from shorting out the bias, their values can be chosen accordingly.

I chose to mismatch the input at low frequency by adding a small blocking capacitor. I could have achieved the same result by playing with an output capacitance, but in the intended application, this amplifier's output match is the more critical of the two. Whether to perform this frequency shaping at the

Table 8

A matching stub at the input to the MMIC improves high-frequency gain and lowers high-end input VSWR.

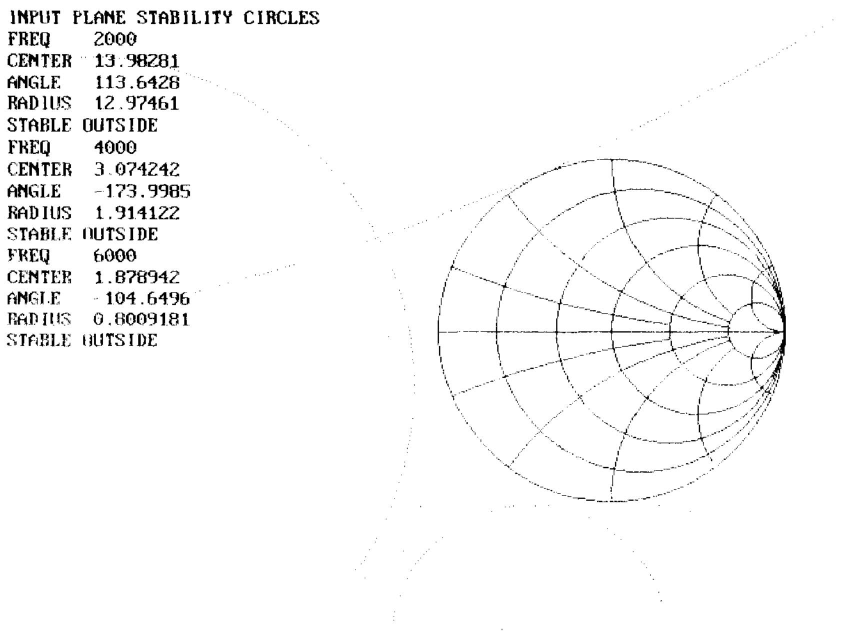
```
This file is : 2-6ghz.amp

circuit 2-6ghz.amp
ost aa dg 50 ?46        6000
two bb sp 50 '\circuits\star\data\msa0835.836
res cc pa  100
cax aa cc
output
gph aa s21 50 0 20
gph aa s12 50 -20 0
smh aa s11 50
smh aa s22 50
freq
swp 2000 6000 21
opt
5800 6000 s11<-20

Run of 2-6ghz.amp  === SuperStar ===    Wed Aug 31 03:35:59 1988

FREQ(MHz) INPUT VSWR   S21 dB< ANG     S12 dB   OUTPUT VSWR     K

 2000.00    3.019    14.631< 42.531   -22.483     1.437      1.008833
 2200.00    3.008    13.824< 38.995   -22.077     1.430      1.04607
 2400.00    3.015    12.979< 34.862   -21.679     1.428      1.085668
 2600.00    2.989    12.204< 30.282   -21.301     1.417      1.130241
 2800.00    2.938    11.538< 25.280   -20.927     1.404      1.172316
 3000.00    2.913    10.914< 19.478   -20.538     1.406      1.202683
 3200.00    2.886    10.379< 14.976   -20.176     1.429      1.221843
 3400.00    2.876    9.8758< 9.8599   -19.803     1.459      1.231237
 3600.00    2.822    9.4172< 4.7415   -19.405     1.503      1.239554
 3800.00    2.715    8.9919<-.32252   -18.982     1.563      1.250228
 4000.00    2.616    8.6167<-6.0143   -18.545     1.634      1.25047
 4200.00    2.406    8.1973<-10.443   -18.203     1.715      1.290602
 4400.00    2.213    7.7933<-15.474   -17.846     1.807      1.323193
 4600.00    2.034    7.4171<-21.180   -17.473     1.909      1.345431
 4800.00    1.869    7.0851<-27.628   -17.087     2.024      1.353741
 5000.00    1.719    6.8180<-34.864   -16.686     2.154      1.343959
 5200.00    1.478    6.5268<-41.567   -16.296     2.249      1.366322
 5400.00    1.295    6.2500<-49.076   -15.897     2.359      1.364209
 5600.00    1.237    5.9937<-57.456   -15.499     2.485      1.334229
 5800.00    1.377    5.7642<-66.747   -15.112     2.627      1.273276
 6000.00    1.665    5.5668<-76.951   -14.752     2.781      1.179243
```



```
INPUT PLANE STABILITY CIRCLES
FREQ    2000
CENTER  13.98281
ANGLE   113.6428
RADIUS  12.97461
STABLE OUTSIDE
FREQ    4000
CENTER  3.074242
ANGLE   -173.9985
RADIUS  1.914122
STABLE OUTSIDE
FREQ    6000
CENTER  1.878942
ANGLE   -104.6496
RADIUS  0.8009181
STABLE OUTSIDE
```

Fig 6—Input stability circles for swamped MMIC show instability regions now all fall outside the limits of real terminating impedances.

input or the output is thus analogous to the decision of whether to swamp for stability at the input or output: it depends upon the application.

As indicated in Table 10, a 1 pF input capacitance lowers the 2-GHz gain by fully four and a half dB, without impacting the gain at the high end. As you would expect by now, this capacitance interacts with other component values in the circuit, and further tweaking of the matching stubs may be necessary to achieve optimum performance. Fig 10 shows the results of that tweaking: a nominal 7.5 dB of gain, with reasonable flatness, across the entire 2- to 6-GHz band. Note that output match is excellent at all frequencies, while input match degrades at the low end of the band.

STEP 7: Verify Stability of the Final Design

We've very nearly completed the wideband microwave amplifier design. All that remains is to once again perform a stability circle analysis, to ensure that our tweaking and peaking hasn't inadvertent-

Table 9

An additional output matching stub improves high-frequency output VSWR, and further raises high-end gain.

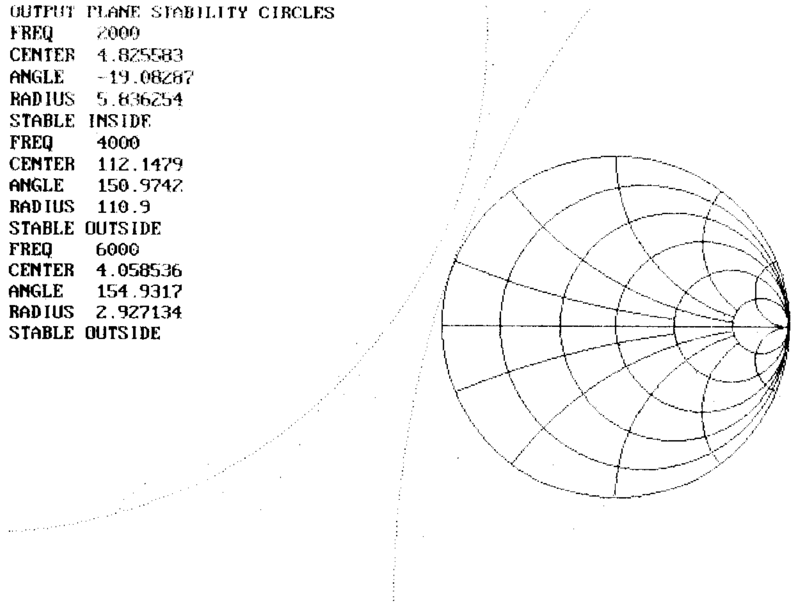
```
This file is : 2-6ghz.amp

circuit 2-6ghz.amp
ost aa dg 50 ?46       6000
two bb sp 50 '\circuits\star\data\msa0835.836
res cc pa  100
trl dd dg 50 ?41       6000
ost ee dg 50 ?47       6000
cax aa ee
output
gph aa s21 50 0 20
gph aa s12 50 -20 0
smh aa s11 50
smh aa s22 50
freq
swp 2000 6000 21
opt
5800 6000 s22<-40

Run of 2-6ghz.amp  === SuperStar ===    Wed Aug 31 03:40:55 1988

 FREQ(MHz)   INPUT VSWR   S21 dB< ANG      S12 dB   OUTPUT VSWR     K

  2000.00      3.118    14.637< 22.188   -22.478     1.427      1.008833
  2200.00      3.141    13.835< 16.519   -22.066     1.410      1.04607
  2400.00      3.186    12.996< 10.238   -21.663     1.397      1.085668
  2600.00      3.205    12.207< 3.5263   -21.298     1.411      1.130241
  2800.00      3.203    11.507<-3.5604   -20.959     1.463      1.172316
  3000.00      3.236    10.845<-11.411   -20.607     1.529      1.202683
  3200.00      3.264    10.294<-17.941   -20.261     1.575      1.221843
  3400.00      3.321    9.7775<-25.065   -19.901     1.623      1.231237
  3600.00      3.337    9.3096<-32.134   -19.513     1.677      1.239554
  3800.00      3.292    8.8820<-39.088   -19.092     1.734      1.250228
  4000.00      3.257    8.5150<-46.648   -18.647     1.787      1.25047
  4200.00      3.045    8.1278<-52.971   -18.273     1.817      1.290602
  4400.00      2.845    7.7721<-59.918   -17.867     1.837      1.323193
  4600.00      2.656    7.4631<-67.586   -17.427     1.844      1.345431
  4800.00      2.482    7.2207<-76.071   -16.951     1.834      1.353742
  5000.00      2.327    7.0694<-85.459   -16.435     1.805      1.343959
  5200.00      2.028    6.9478<-95.092   -15.875     1.656      1.366322
  5400.00      1.811    6.8563<-105.94   -15.291     1.487      1.364209
  5600.00      1.727    6.7888<-118.20   -14.704     1.301      1.334229
  5800.00      1.862    6.7290<-132.02   -14.148     1.104      1.273276
  6000.00      2.311    6.6458<-147.49   -13.673     1.105      1.179243
```



```
OUTPUT PLANE STABILITY CIRCLES
FREQ    2000
CENTER  4.825583
ANGLE   -19.08287
RADIUS  5.836254
STABLE INSIDE
FREQ    4000
CENTER  112.1479
ANGLE   150.9742
RADIUS  110.9
STABLE OUTSIDE
FREQ    6000
CENTER  4.058536
ANGLE   154.9317
RADIUS  2.927134
STABLE OUTSIDE
```

Fig 7—Output stability circles for the swamped MMIC further suggest unconditional stability.

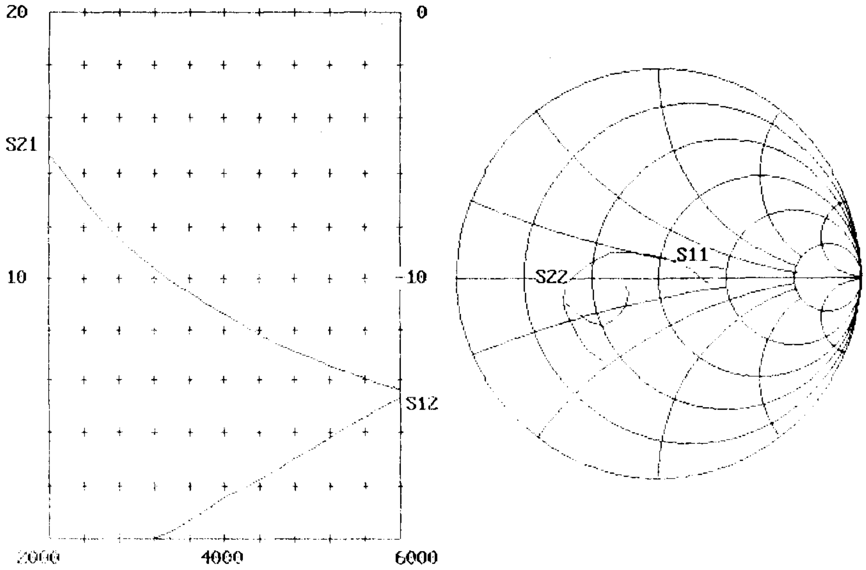


Fig 8—Input matching results in some flattening of the gain curve, by reducing input reflection losses at the higher frequencies.

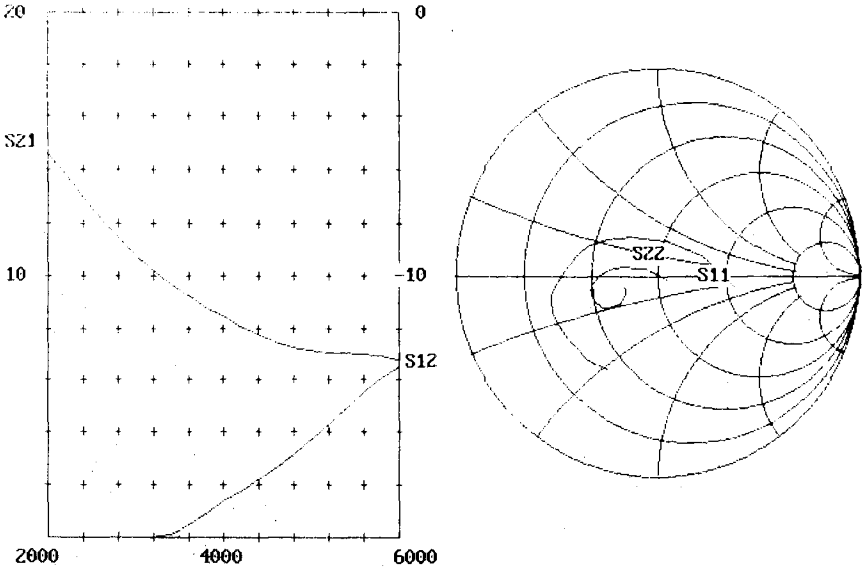


Fig 9—With both input and output matching optimized for high-frequency performance, noticeable flattening of the gain curve begins to occur.

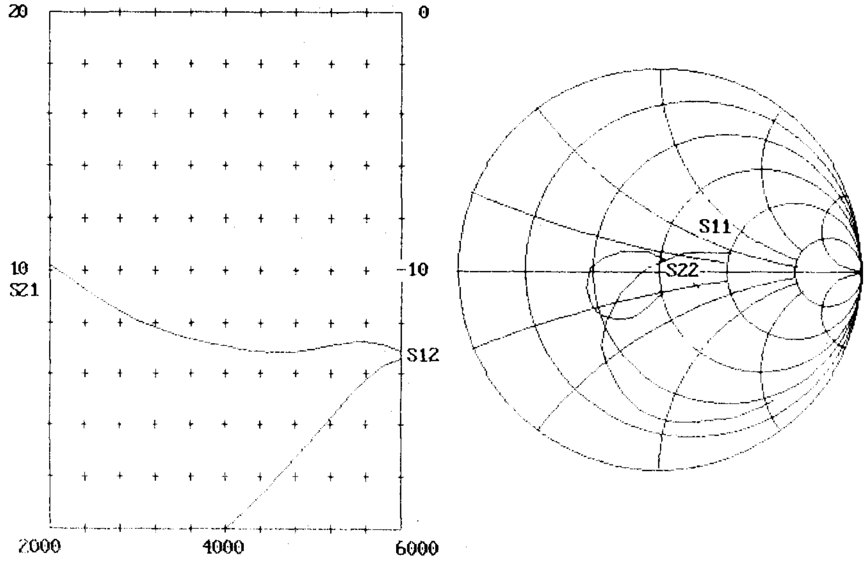


Fig 10—A final tweak to the input trimmer and matching stubs results in fairly flat gain performance across 1½ decades of frequency.

Table 10

Additon of a small input coupling capacitor rolls off low-frequency gain noticably.

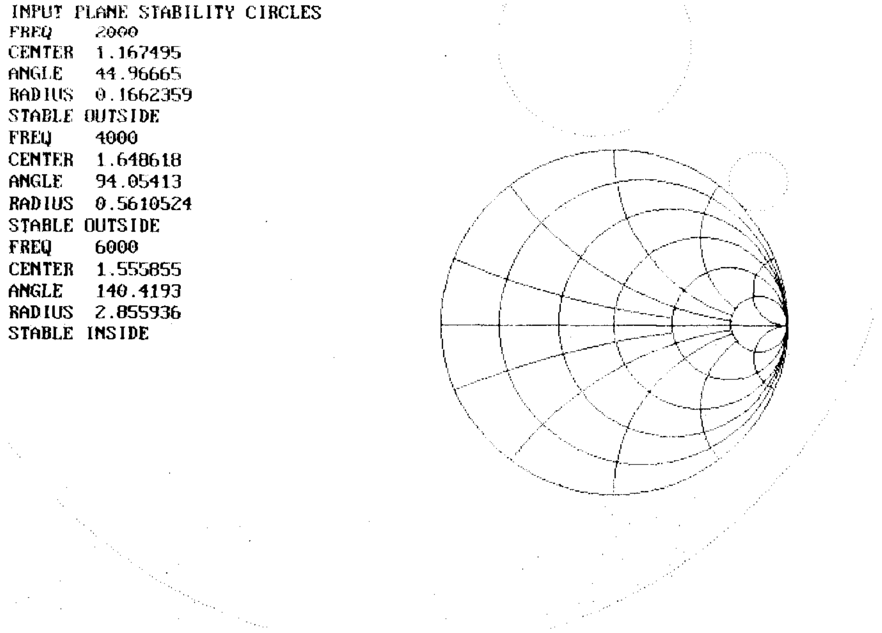
```
This file is : 2-6ghz.amp

circuit 2-6ghz.amp
cap aa se ?1.002985
ost bb dg 50 ?44.42182 6000
two cc sp 50 '\circuits\star\data\msa0835.836
res dd pa  100
trl ee dg 50 ?44.92084 6000
ost ff dg 50 ?48.92987 6000
cax aa ff
output
gph aa s21 50 0 20
gph aa s12 50 -20 0
smh aa s11 50
smh aa s22 50
freq
swp 2000 6000 21
opt
2000 6000 s21=8
```

```
Run of 2-6ghz.amp  === SuperStar ===   Wed Aug 31 03:48:17 1988

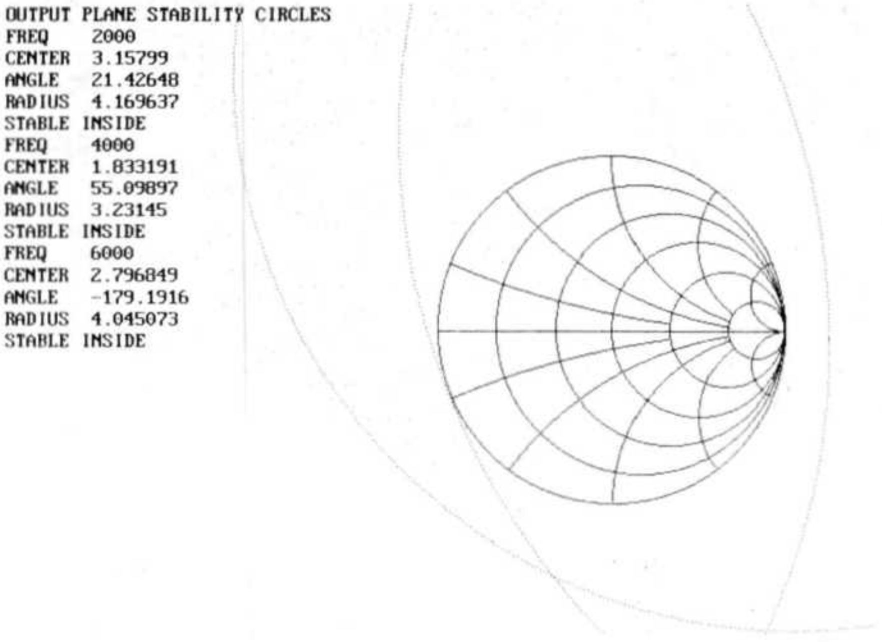
 FREQ(MHz)  INPUT VSWR    S21 dB< ANG      S12 dB    OUTPUT VSWR      K

  2000.00     13.26      10.163< 56.483   -26.952      1.214      1.008836
  2200.00     12.01      9.7496< 49.921   -26.152      1.277      1.046073
  2400.00     11.05      9.2523< 42.874   -25.406      1.338      1.085672
  2600.00     10.14      8.7911< 35.547   -24.714      1.436      1.130244
  2800.00     9.268      8.4101< 27.972   -24.056      1.575      1.172319
  3000.00     8.576      8.0453< 19.716   -23.407      1.719      1.202686
  3200.00     7.968      7.7719< 12.561   -22.783      1.813      1.221846
  3400.00     7.471      7.5189< 4.8782   -22.160      1.902      1.23124
  3600.00     6.947      7.3098<-2.8966   -21.513      1.990      1.239557
  3800.00     6.367      7.1392<-10.717   -20.835      2.075      1.250231
  4000.00     5.842      7.0261<-19.108   -20.136      2.150      1.250472
  4200.00     5.094      6.9043<-26.697   -19.496      2.176      1.290605
  4400.00     4.424      6.8101<-34.946   -18.829      2.181      1.323195
  4600.00     3.816      6.7617<-43.989   -18.129      2.160      1.345433
  4800.00     3.260      6.7810<-53.965   -17.391      2.109      1.353743
  5000.00     2.752      6.8930<-65.024   -16.611      2.024      1.343961
  5200.00     2.101      7.0277<-77.280   -15.796      1.779      1.366323
  5400.00     1.559      7.1445<-91.214   -15.003      1.511      1.36421
  5600.00     1.139      7.1984<-107.05   -14.294      1.253      1.334229
  5800.00     1.369      7.1200<-124.81   -13.757      1.192      1.273277
  6000.00     2.128      6.8292<-144.20   -13.490      1.522      1.179243
```



```
INPUT PLANE STABILITY CIRCLES
FREQ    2000
CENTER  1.167495
ANGLE   44.96665
RADIUS  0.1662359
STABLE OUTSIDE
FREQ    4000
CENTER  1.648618
ANGLE   94.05413
RADIUS  0.5610524
STABLE OUTSIDE
FREQ    6000
CENTER  1.555855
ANGLE   140.4193
RADIUS  2.855936
STABLE INSIDE
```

Fig 11—A final check of input stability circles assures input unconditional stability.



```
OUTPUT PLANE STABILITY CIRCLES
FREQ     2000
CENTER   3.15799
ANGLE    21.42648
RADIUS   4.169637
STABLE  INSIDE
FREQ     4000
CENTER   1.833191
ANGLE    55.09897
RADIUS   3.23145
STABLE  INSIDE
FREQ     6000
CENTER   2.796849
ANGLE    -179.1916
RADIUS   4.045073
STABLE  INSIDE
```

Fig 12—Similarly, output stability circles all fall clear of the Smith Chart, suggesting the stability design goal has been satisfied.

ly pushed our active device toward oscillation. Figs 11 and 12 show the input and output stability circles, respectively. They confirm that this wideband amplifier will remain unconditionally stable across its entire operating frequency range, for any combination of source and load impedances. Were the stability circles to intersect the Smith Chart at any point, the only practical alternative would be to slightly lower the value of the swamping resistor, and start the matching process all over again. Clearly, this iterative process is better performed at the computer than at the workbench!

References

[1] Vatt, Greg, "Computer Aided UHF Preamplifier Design," *Ham Radio*, Oct 1982, p 28.

[2] Shuch, H. Paul, "Microstripline Preamplifiers for 1296 MHz," *Ham Radio*, Apr 1975, p 12.

[3] Shuch, H. Paul, "Low-Cost 1296 MHz Preamplifier," *Ham Radio*, Oct 1975, p 42.

[4] Shuch, H. Paul, "Solid State Microwave Amplifier Design," *Ham Radio*, Oct 1976, p 40.

[5] Shuch, H. Paul, "Smith Chart Part 2: The Scalar Approximation," *Proceedings of the 21st Conference of the Central States VHF Society*, Aug 1987, p 118.

[7] SuperStar is available from Circuit Busters, Inc, 1750 Mountain Glen, Stone Mountain, GA 30087.

[7] Super Compact is available from Compact Software, 483 McLean Blvd, Paterson, NJ 07504.

[8] Touchstone is available from EEsof Inc, 5795 Lindero Canyon Road, Westlake Village, CA 91362.

VHF+ Technology

By Geoff Krauss, WA2GFP
16 Riviera Drive
Latham, NY 12110

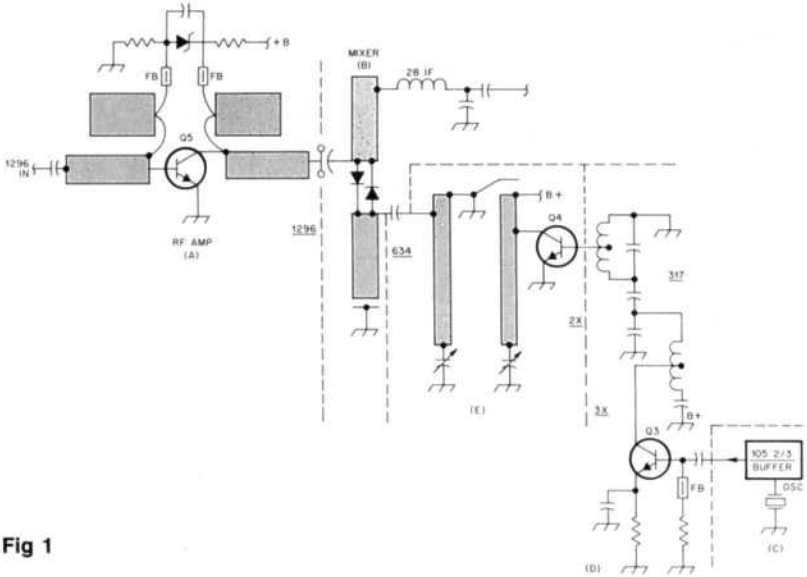


Fig 1

I received a request from Bill Wesslund, W0BJ, for any available information on either an Alfred 503 TWT Amp (probably from the '50s or '60s) or a much newer Logimetrics 101/XH TWTA (1 watt, 8-18 GHz) using a Litton L2384-02 TWT. Bill tried the manufacturer, but they wanted $100 for a copy of the manual! Contact me if you can help out on this one.

PROPER MICROWAVE CHIP CAPACITORS

I received a batch of chip components for the WB5LUA SHF preamps from Kent Britain, WA5VJB (whose call also appears on the preamp PC boards that I have). Kent apparently heard that I was going to build a set of the LNAs and wanted to be sure that I had some good chips to do it with, including several styles of 10-GHz bypass and coupling capacitors. Thanks, Kent. This again brings up an extremely important point: VHF+ gear requires the use of good (ie, microwave porcelain) chip capacitors! Depending on the particular use and circuit, one might be able to use a "regular" carbon resistor instead of a chip resistor, *but* I cannot think of a bypassing or coupling task, especially above 1 GHz, in which anything but a good microwave chip capacitor should be used. (See Bob Atkins' explanation in his "The New Frontier" column in the August 1989 issue of *QST*.) Knowing that you have to use chip caps still does not tell you how to find low-loss units. Many of the chip capacitors available today are not low-loss microwave units. They are merely chip components made for affixation to PC boards using highly automated surface-mounting technology (SMT) and are for use, at most, at HF frequencies. A sure tip-off is a non-white dielectric and/or a "large" size (microwave chip caps are almost always 0.05- or 0.10-inch units). Even knowing these facts does not help as there are many non-low-loss units with the right size, shape and color! Once you put them into a VHF+ unit, it becomes almost impossible to isolate to a single component if you later test out with decreased gain, increased noise figure, etc. How then do you make sure that you put a proper chip cap in the circuit right from the start? By obtaining chip caps from a known good source! There are a few fellow VHF+ers who sell chip caps and know that they are proper units; there are other who do not. I have personally seen the operator of one small ham-oriented component supply business buying his chip caps in bulk from other sellers at hamfests. Does he really know who made the chips, or what they are? No offense, guys, but there are certain projects which, if I'm about to put lots of dollars and long hours into building, I want to be absolutely sure that the components are proper. One way is to buy directly from the manufacturer. Of course, the minimum buy may be too steep for a small project, unless you do it with other builders. This is not always possible. Another way is to purchase a so-called evaluation set of components from a manufacturer. For example, there are two different muRata/ERiE Microwave Chip Capacitor Sample Kits (MA18-001 or -002) each with five pieces for $50, postpaid, from FrontLine Marketing Systems, Inc, 4839 Martin Court, Suite 6, Smyrna, GA 30081. Even if Kent had not sent me some goodies, with the -001 kit I would have had proper chips to do my 3.4/5.6/10.4-GHz building and still have plenty left for other projects.

Further on the WB5LUA 10.4 GHz LNAs. Al Ward advises that the specified ATF-13135 devices are the ATF-13100 chip in the micro-X, or "35," ceramic package and with a standard lead length of about 0.175 inches, as required for proper source lead dress. These devices may be hard to find, although DownEast Microwave may have some available. Also, there is apparently a more available ATF-13136 surface-mount version with leads which are only 0.040 inches long and therefore too short for direct use. Al suggests that small eyelets of 0.025- to 0.050-inch diameter be pushed through the PC board so that the short leads can be soldered to the eyelet end on the microstrip side of the board. (Actually, I prefer to do this on all microwave device through-board leads rather than rely on plated-through holes or extension of leads through cut slits because removal or replacement of the device is much easier when necessary. Of course, that is *not* appropriate in the LUA series of preamps which were designed to have specific lead lengths due to source lead through-board routing!).

SOME THOUGHTS ON VHF+ CONSTRUCTION

While putting together the new 23-cm LNA I mentioned in my last column, I decided to also get an extra 23-cm receiver converter ready in case it became needed in this summer's round of contests. "Easy task," I thought. I had the test equipment all set up and had an untested converter on a shelf, built from an article in the March 1982 issue of *Radio and Electronics World*, an English publication. The kit was apparently made available by a European group, if the parts are any indicator. The converter (Fig 1) has a microstrip RF amplifier stage (A), a passive microstrip harmonic mixer (B) and a four-stage LO chain (C and D), with microstrip double-pole filter in the last (half-injection-frequency) multiplier (E). Simple and easy to get operating, right? I spent six weeks of lunch hours correcting problems with each active stage. The troubles I encountered are worth commenting upon as they are typical of problems that are often encountered with *any* project, and may save other VHF+ers from suffering all kinds of frustration (and possibly give up VHF+ construction and/or operation).

Rule 1: Unless you really know what you are doing, build a unit in separate stages. If I were designing a new converter, from scratch, I would have at least three separate boxes (RF amp, mixer, LO chain) with interconnecting cables. Sure, the extra cables and connectors add some cost and extra space, but its worth will become apparent the first time you have to repair the unit.

Rule 2: If you do build a unit with many/all stages on a single PC board, build and test each stage in sequence, *before* going on to the next stage. I applied power to the converter, nothing happened! (It could have been worse—I could have smoked something.) A lack of LO signal (checked with a spectrum analyzer at the mixer LO input) started me hunting backwards through the LO chain—a difficult task since four stages

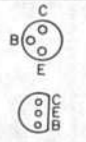


Fig 2

were spread all over a narrow strip of PC board. After several days and much removal of parts, I found the trouble in the 5th-overtone oscillator. It might have taken 10 minutes to do the same evaluation if the unit were in separate, cabled-together stages.

Rule 3: Check and recheck each part and its location *before* placement into the stage. In repairing the oscillator, the problem was that the board was laid out for a transistor having the almost-standard EBC lead circle (left side of Fig 2). But almost is not good enough—the actual device had a different (BEC) basing circle. There was no base pictorial in the kit documentation and the layout drawing was kind of fuzzy. Because the device had a European number it was impossible to check a catalog and find out which lead was which. Hence, I had to figure out the problem by noting the weird DC voltages at the device leads and pondering for several days.

Rule 4: Use proper parts. Give some thought not only to the obvious requirements, but also to anything special (do you need to use silver-bearing solder with chip capacitors, etc). For example, once I got the oscillator transistor soldered into the circuit in the proper lead arrangement, I found that although the bias currents and voltages were now reasonable, there was no oscillation. "Aha, adjust the oscillator coil," I said—but the coil core was metric and too large for my 0.075-inch hex tool, but too small for the 0.100-inch hex. Since there are the standard US core sizes, I had to cut down a pencil to jam-fit the core so that I could adjust the coil until oscillation started.

Rule 5: Try to understand the specifics of the design so that you can make changes if necessary. For example, the buffer stage transistor was also soldered in with the wrong basing (same problem). In correcting this, the device died. European device, no replacement. Luckily, it is a class-A amp at 105 MHz; I grabbed a 20-200 MHz ubiquitous MPS-3563 (with basing information printed right on the case!), soldered same into the circuit and . . . fixed! Example 2—the doubler from 317 MHz to 634 MHz produced LO power −27 dB below requirement! Bad device (a ZTX3866 plastic-pac version of the 2N3866, 1-watt UHF amp device) found; replaced with a good metal-can 2N3866 and LO power was up to −13 dB down. A check with a spectrum analyzer shows most output power at input frequency. After considerable thought, the stage was modified to add some emitter bias (see Fig 3) and the device changed to a more modern MRF965. By adjusting the emitter resistance (bypassed by a good microwave chip cap) the device self-bias was adjusted for best conduction angle and power at the desired harmonic was brought up to spec.

Conversely, know when *not* to modify something. For example, I would not change the harmonic mixer just because this type of mixer is not often seen in US amateur circles. True, the LO-to-RF isolation is low and would not be bad if we were back in the days of direct-input-to-mixer converters where the unit did not have the reverse gain of the RF amp to add additional isolation and really reduce the amount of LO signal leaking out of the 1296 input. Even better, this form of mixer does away with the need for the highest-frequency last doubler in the LO chain. This is a difficult stage to provide so its disappearance is not much missed. (Look for harmonic mixers to become more prevalent in receive-only applications above 1 GHz in the future.)

Rule 6: Don't be afraid to improvise. For example, the unit was designed for 10-V dc operation, but best LO operation is at 12 V dc. The only adverse effect of 12 V is the drastic instability of the RF amp—it takes off and becomes a 90-MHz power oscillator! Short of scraping it off the board, the only practical fix is to borrow an active-bias network (Fig 4) from my old-tricks file to keep the collector voltage below 10 V so that the device does not go into breakdown (also allows the current to be varied to bring the original converter NF of 4.6 dB down to 2.1 dB).

Keep these points in mind as my next column continues consideration of what is state-of-the-art above 2 GHz.

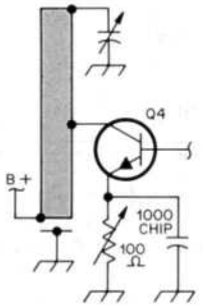


Fig 3

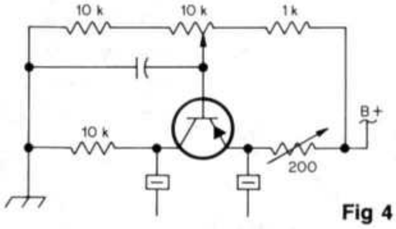


Fig 4