Plugboard Development of the VascuDOP$_{tm}$

Today's electronic engineers make use of computer simulations to design and even test complicated digital circuits. Such an approach applied to low-noise analog design can be akin to the Zero card in the Tarot card deck, however. That card depicts a young man confidently strolling along, not aware that he is about to step off a cliff... Analog noise sources and feedback loops are hard to simulate in Spice. They must be found and eliminated in real-world conditions. Though considered a tool for the amateur electronic hobbyist, a common commercial "plugboard" can be a great testbed for low-noise, high-gain analog design. If the circuit will function satisfactorily on a plugboard, it should be even better and more stable when transferred to a properly-designed printed circuit board. Such was the case in the development of the VascuDOP.

Equally important with the physical plugboard circuit development is a schematic drawing of the circuit kept up-to-date as the design progresses. Today that drawing would likely be done on circuit schematic software, but a pencil-drawn schematic done on good B or C-sized velum sheets can capture the circuit easily and cheaply. Frequent updates showing any circuit additions or changes are imperative. Any errors between the plugboard circuit and schematic may carry over to the final printed circuit design, causing major frustrations.

The VascuDOP was designed using 20th century through-hole components and power distribution techniques. A raw +/- 15 Vdc power supply was needed to accommodate the high voltage requirements for the receiver front end so that the 100X amplified probe signals did not hit the local +/-12V rails and clip. Once mixed, however, the now much smaller signals could be handled with +/-5V rails. To prevent feedback via these 5V rails it was necessary to locally supply each section of the circuit with its own local (and noise-isolating) regulators.

Strict separation of "analog" and "digital" grounds is paramount in low-noise, high-gain circuit design. In the VascuDOP, the "analog" ground was used strictly for the transmitter and front-end of the receiver. But wait - is not the transmitter essentially a *digital* circuit using standard logic chips to develop 5 MHz I and Q signals from a 20 MHz clock? Well yes, that is true, but here we are trying to isolate the synchronized 5 MHz circuitry from the amplified post-mixer audio which could feed back into the small signals at the front end. As the transmitter is, by definition, synchronized with the receiver mixer circuitry, any digital noise developed will be eliminated in the mixing process. Perhaps a better ground nomenclature would be "RF" and "Audio" grounds.

To reduce noise at the Doppler audio output it is advised to use a low-jitter clock for the transmitter, usually a stabilized crystal. Any variation or jitter in the clock frequency will appear in the audio output as random noise. Digital frequency "synthesizers" should not be used because they can cause unwanted "tearing" or "ripping" noise in the audio output as they adjust frequency following their digital feedback loops.

Note the liberal use of small-signal RF transformers in the design of the front end. These transformers not only provide the galvanic standoff requirements for patient safely, but they also are used to transform the 5V digital I and Q signals from the transmitter into +/-5V signals need for full signal amplification in the 4-quadrant multiplier chips that develop the I and Q raw audio. Audio-band transformers are also used to isolate the stereo audio output to earphones or to a computer performing a Fourier transform spectral frequency display.

After the I and Q signals are developed by the mixers, they are filtered to pass only 100Hz to 20 KHz. A 100Hz 6-pole high-pass filter is necessary to attenuate the loud “thump” that occurs when the probe is touched to the skin. Once filtered, the I and Q audio are equalized by identical precision Automatic Gain Control (AGC) circuits. Without good AGC, the following Nippa Phase Rotation Circuit that converts I and Q audio into Forward and Reverse audio will not work well. “Forward” audio frequency is proportional to the flow *toward* the ultrasound probe; “Reverse” audio indicates flow *away* from the probe. For those who want to learn more about how a Nippa circuits works, see Nippa’s original 1975 paper (Nippa JH, et.al, "Phase Rotation for Separating Forward and Reverse Blood Velocity Signals," IEEE Transactions on Sonics and Ultrasonics, vol. 22, no. 5, pp. 340-346, Sept. 1975).

At this point the circuit has developed the I/Q and F/R audio signals. The I/Q signals can be jumper-selected to the isolated audio output if connecting to a computer that requires the I and Q audio signals to produce a directional spectral audio display. Otherwise the F/R signals can be selected for this output. The F/R signals also drive the LM2917 Frequency-to-Voltage circuits after filtering to remove any high-frequency noise and DC offset. These F-V converters develop a frequency display envelope of the forward and reverse signals. A test signal of known frequency can be injected into the input of these F-V converters to adjust the output voltage from the charge pump to accurately represent the detected flow rate in meters per second. An emitter follower transistor in the LM2917 also drives the LED flow rate indicator, Green for forward flow, Red for reverse. Brighter light indicates a faster flow.

A common complaint of Doppler blood flowmeters is that they produce a white noise hiss on the audio outputs even when not detecting any flow. To address this, the now obsolete SM2000 “Hush” chip from Analog Devices was used as a noise reducer of Dolby type. It also incorporated an automatic mute when the detected signal fell to the level of the background hiss. Shaking, tapping, or placing the Doppler probe against the skin would produce a signal large enough to unmute the device. The outputs from the SM2000 provide the audio for the earphone jack and also the LM4861 bridge driver for the 8-Ohm speaker.

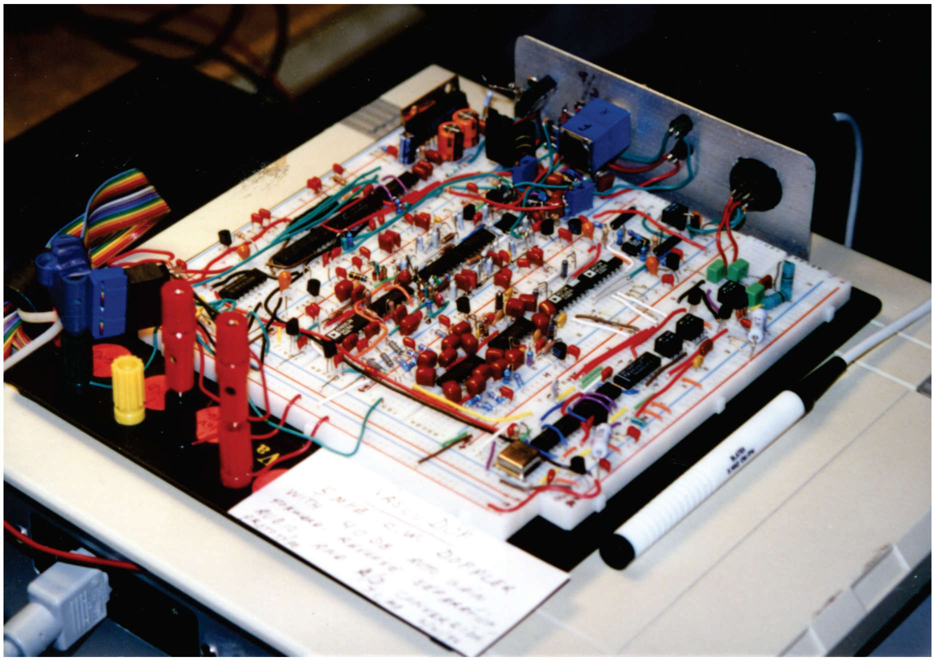


Figure 1. The VascuDOP was developed on a commercial plugboard. Strict isolation of analog and digital grounds and local power regulation was necessary to prevent feedback in this circuit with 110 dB of gain.

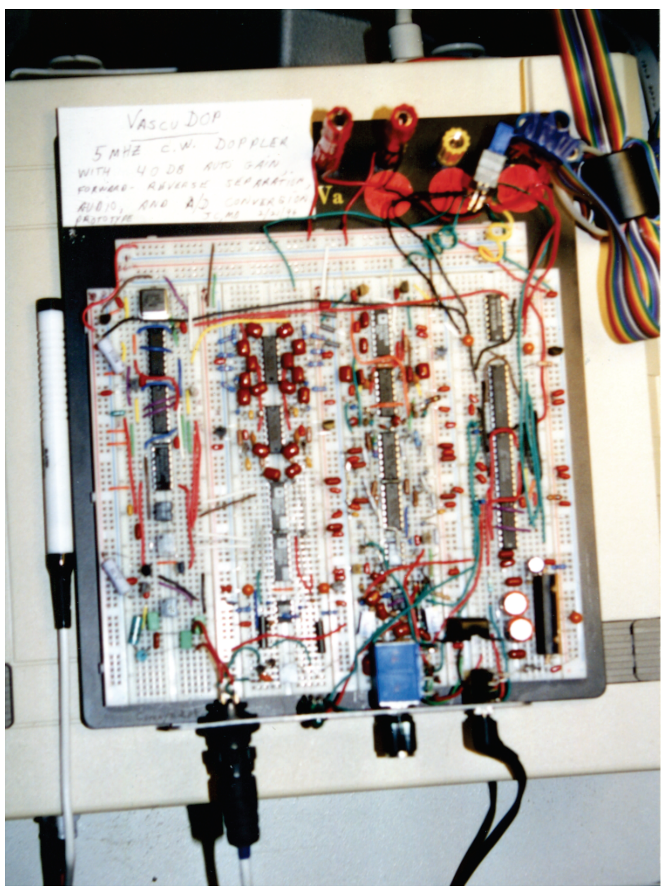


Figure 2. Top view of the VascuDOP plugboard prototype. The transmitter section is on the left.

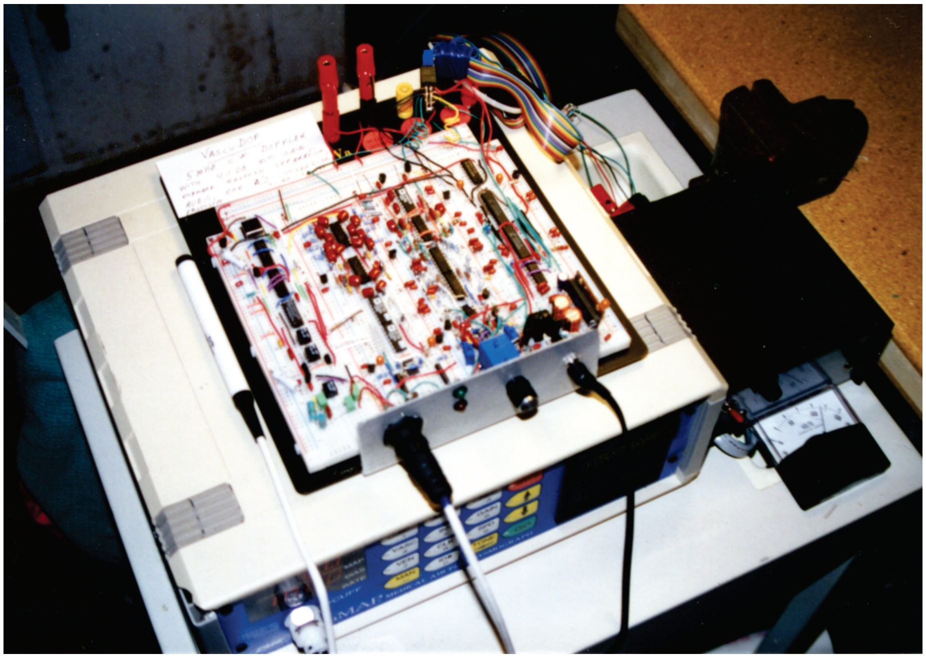


Figure 3. The VascuDOP prototype was developed in close proximity to the original VascuMAP device to make sure there would be no analog noise problems when the two devices were combined in a later design – VascuMAP II.

Sample Tracings taken with the VascuDOP Plugboard Prototype

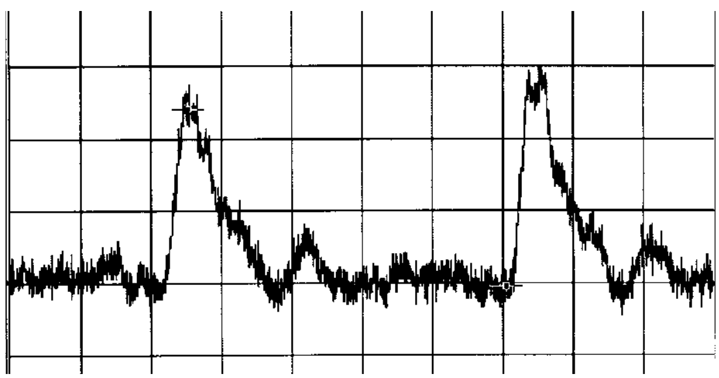


Figure 4 Brachial Artery Flow before Exercise

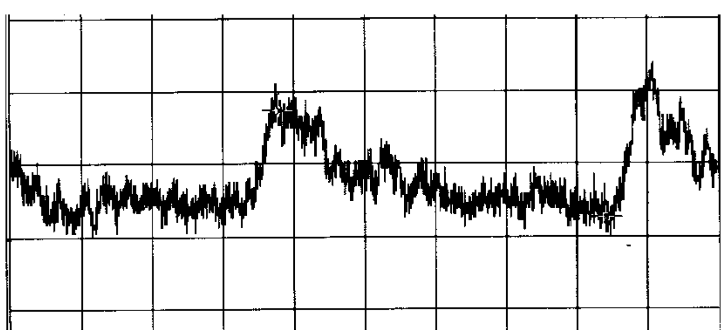


Figure 5 Brachial Artery Flow after Exercise

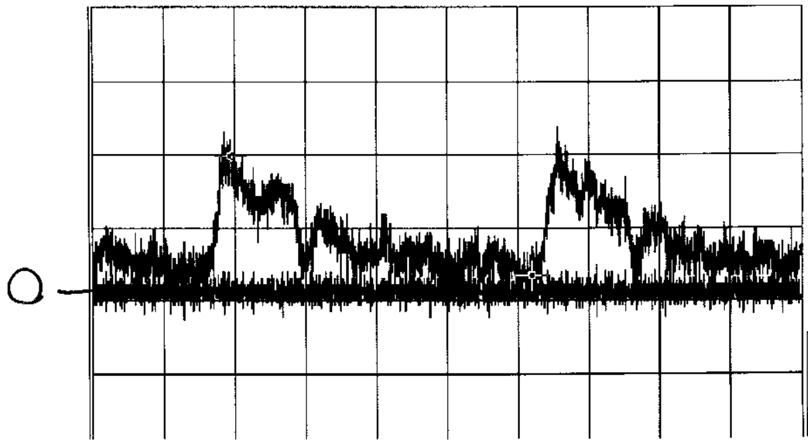


Figure 6 External Carotid Artery

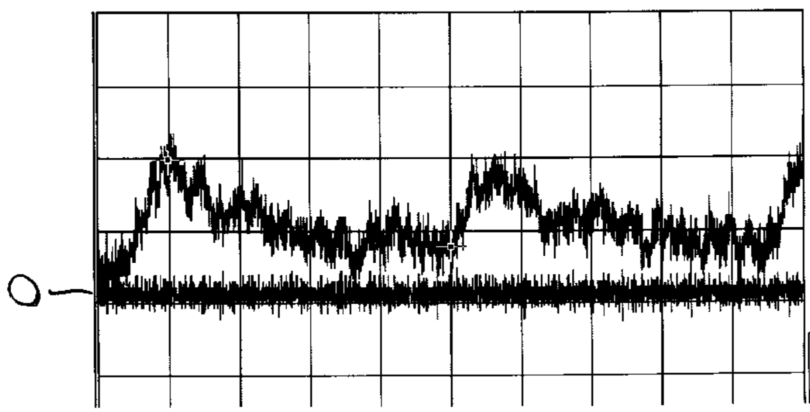
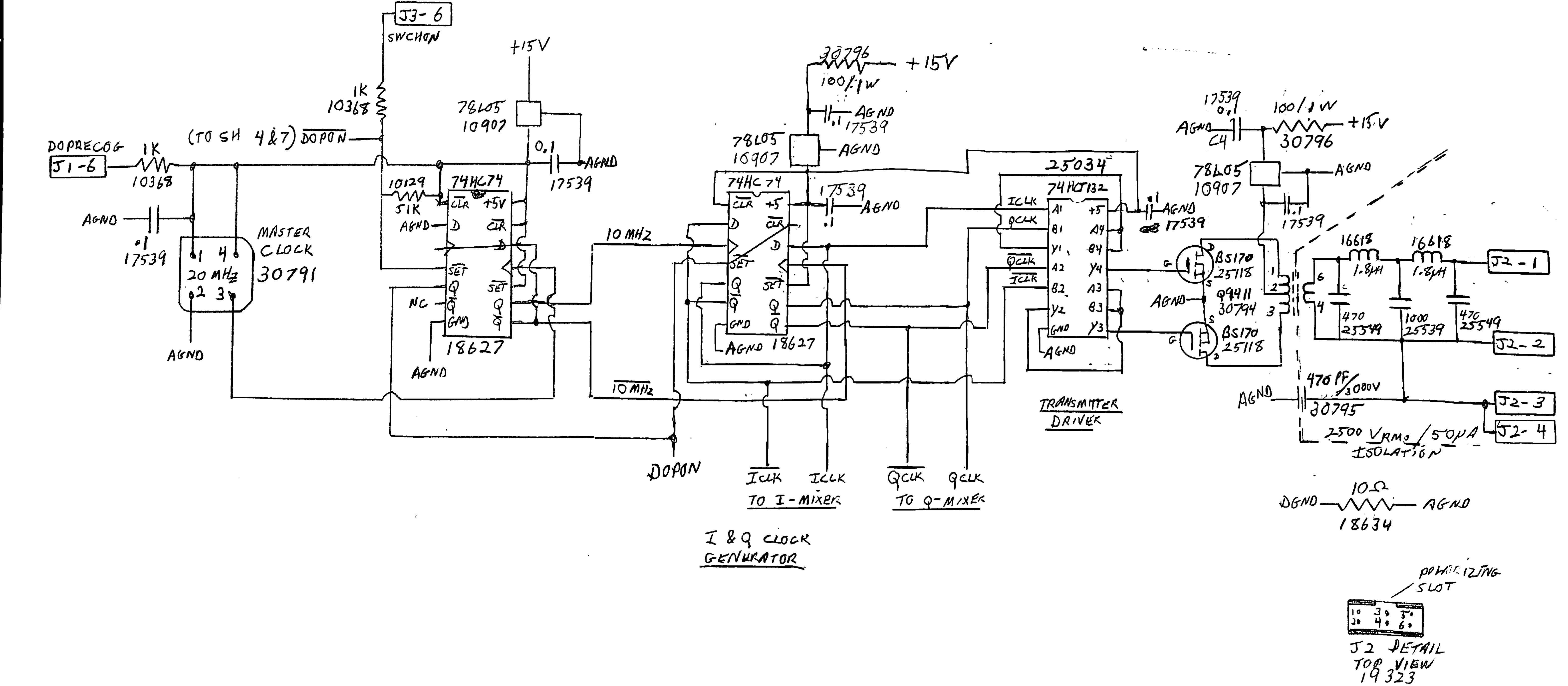


Figure 7 Internal Carotid Artery



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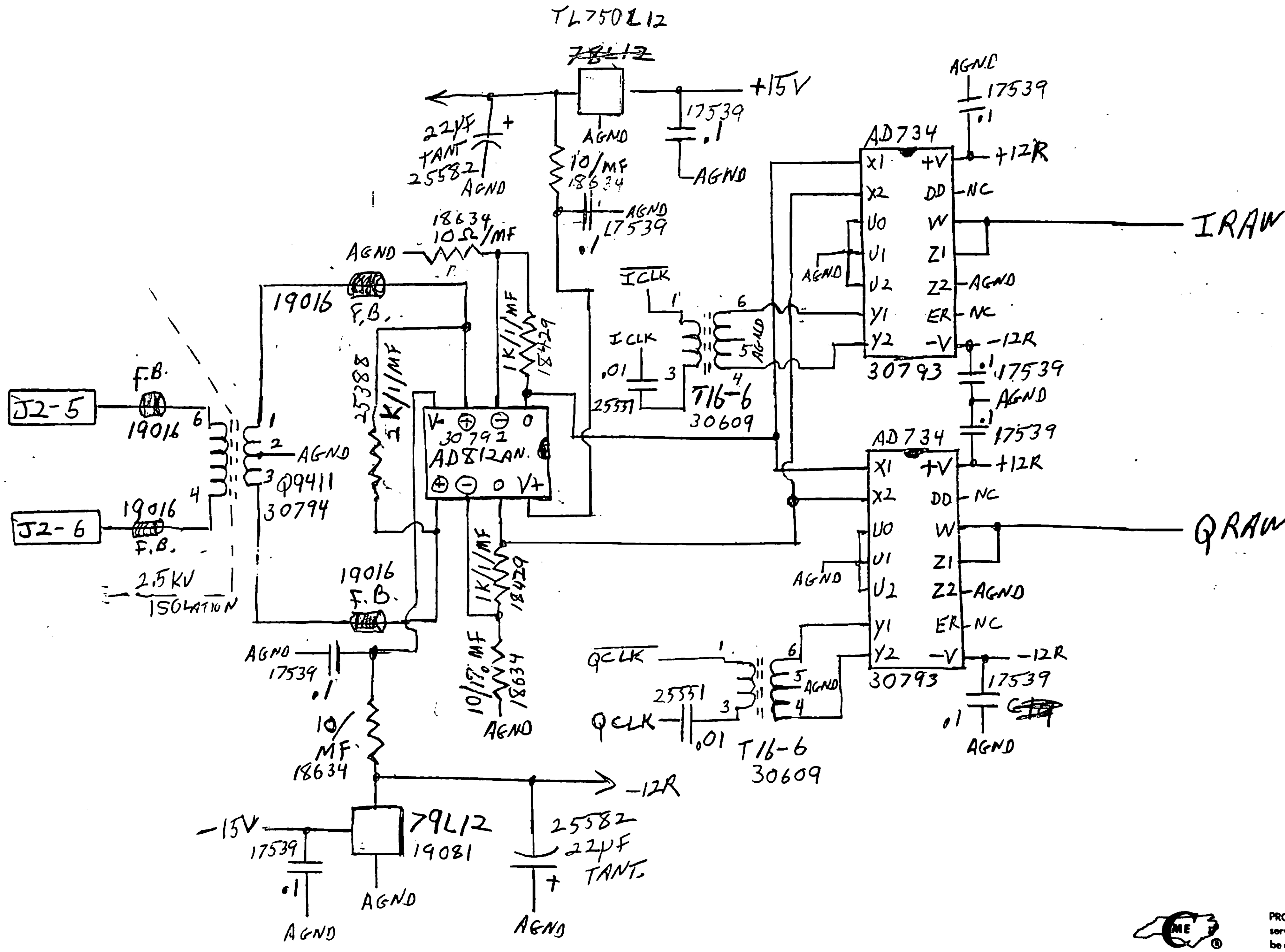
VASCUDOP

5 MHz CW TRANSMITTER

SCALE

APP'D

NO. SC-30780 SH1



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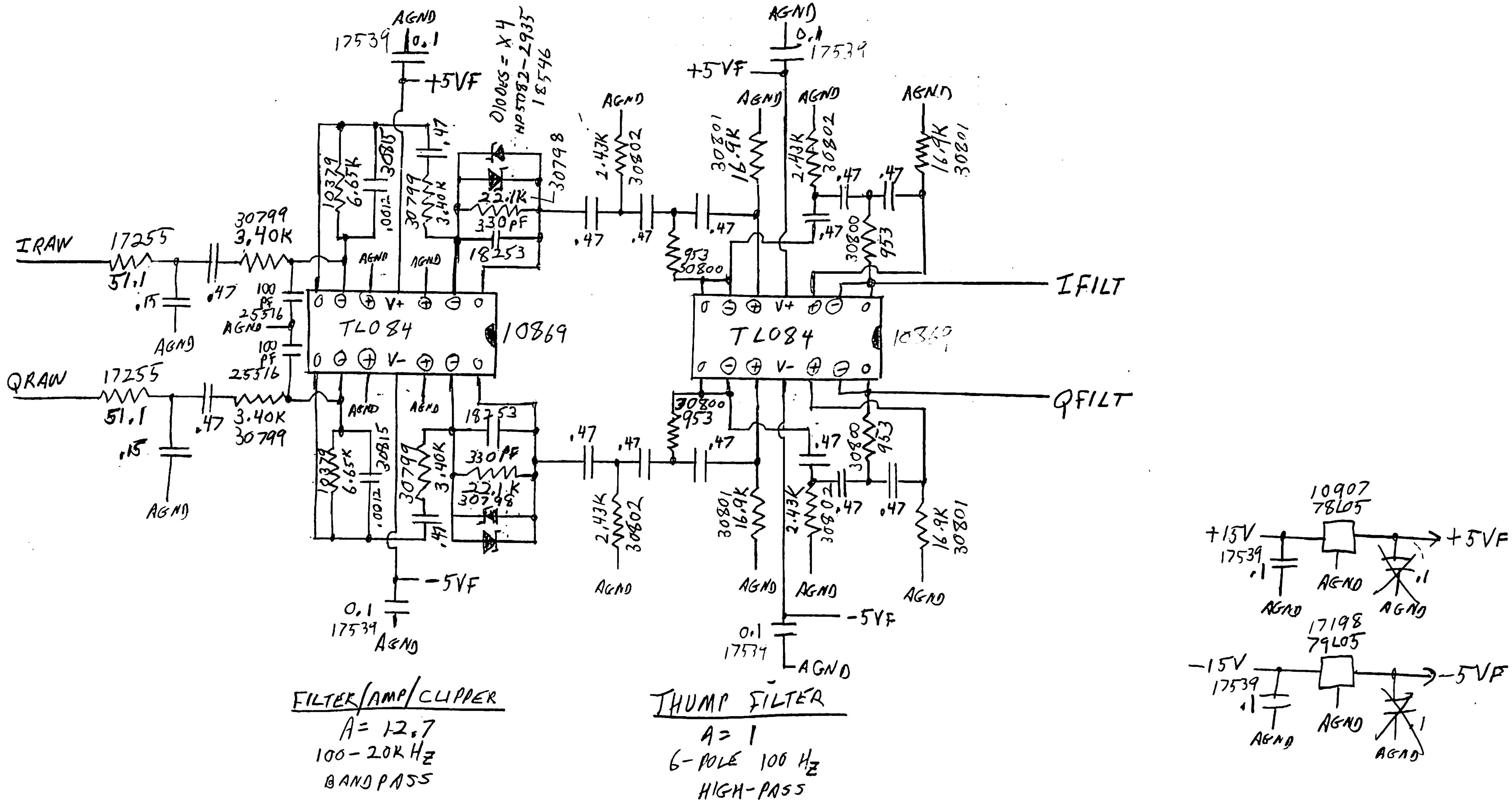
VASCUDOP

RECEIVER FRONT END

SCALE

APP'D

NO. SC-30780 SH 2



NOTE: 0.47μF/5%/50V CAPS = CME# 25545

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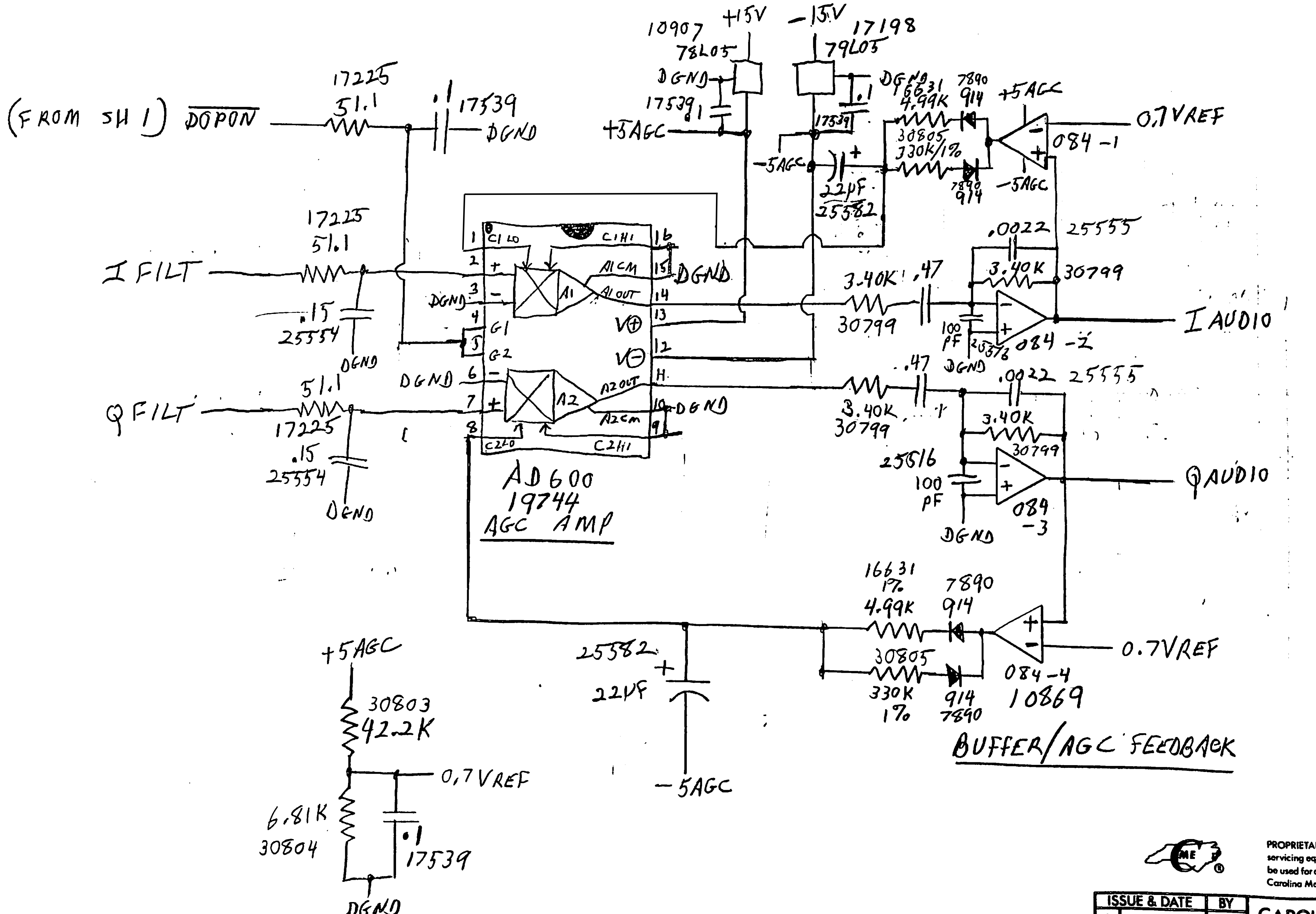
VASCU DOP
AUDIO FILTER SECTION

SCALE
APP'D
NO. SC-30780 SH 3



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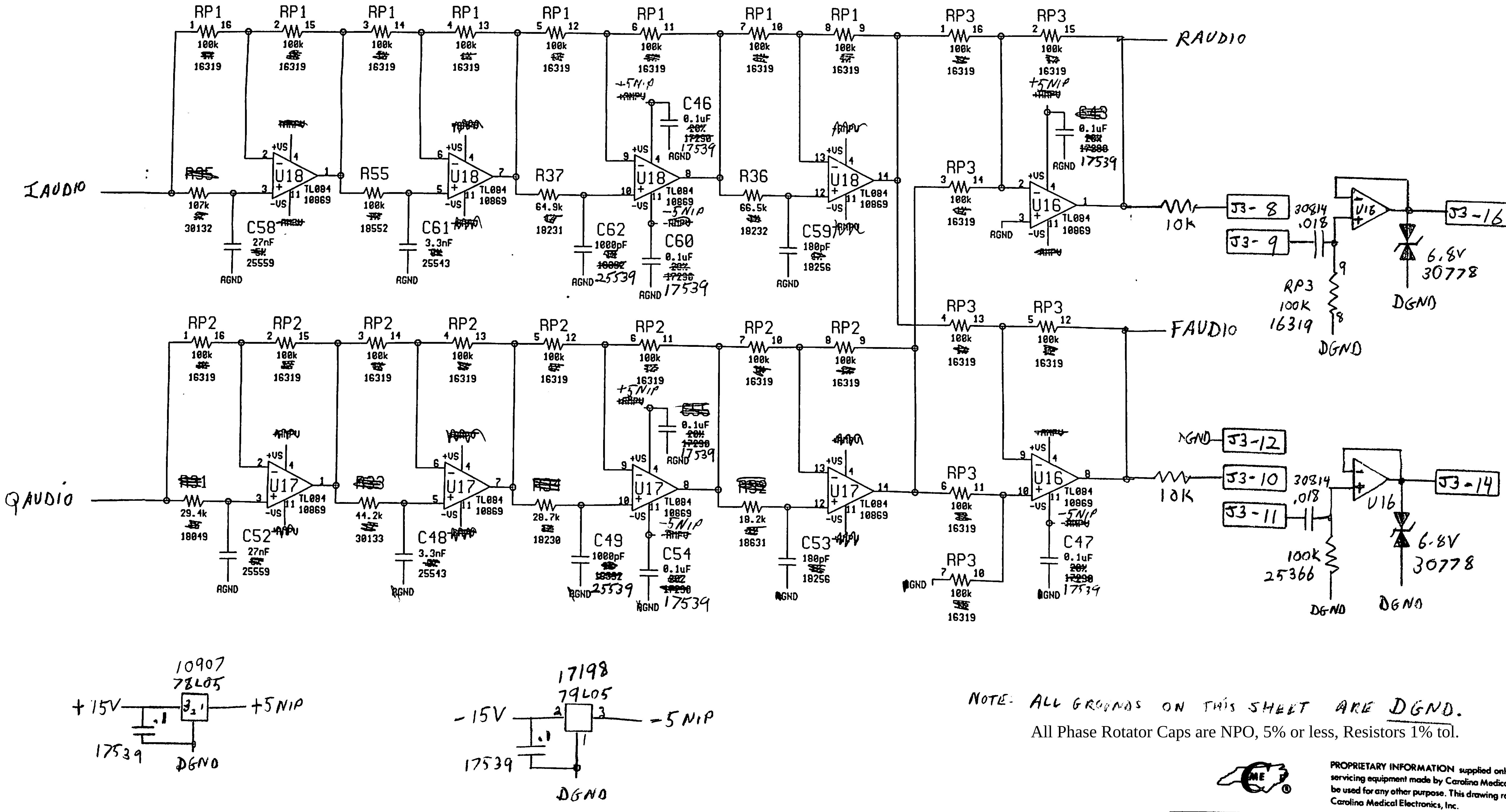
VASCU DOP

AUTOMATIC GAIN CONTROL

SCALE

APP'D

NO. SC-30780 SH 4



NOTE: ALL GROUNDS ON THIS SHEET ARE DGND.

All Phase Rotator Caps are NPO, 5% or less, Resistors 1% tol.

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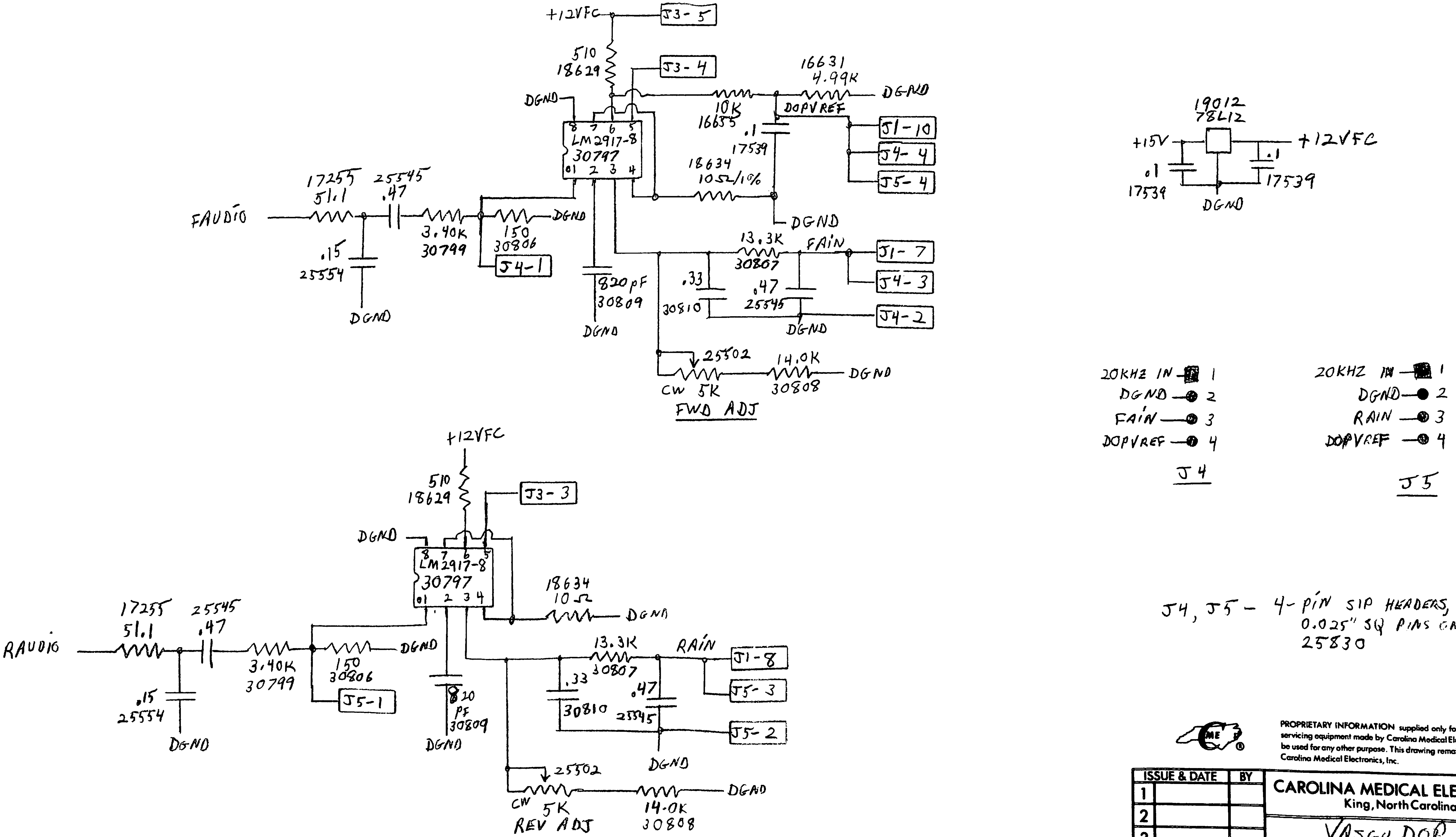
VascuDop
N PPA CIRCUIT

SCALE
APP'D
NO. SC-30780 SH 5



J4, J5 – 4-PIN SIP HEADERS, 0.025" SQ PINS ON 0.1" CNTRS 25830

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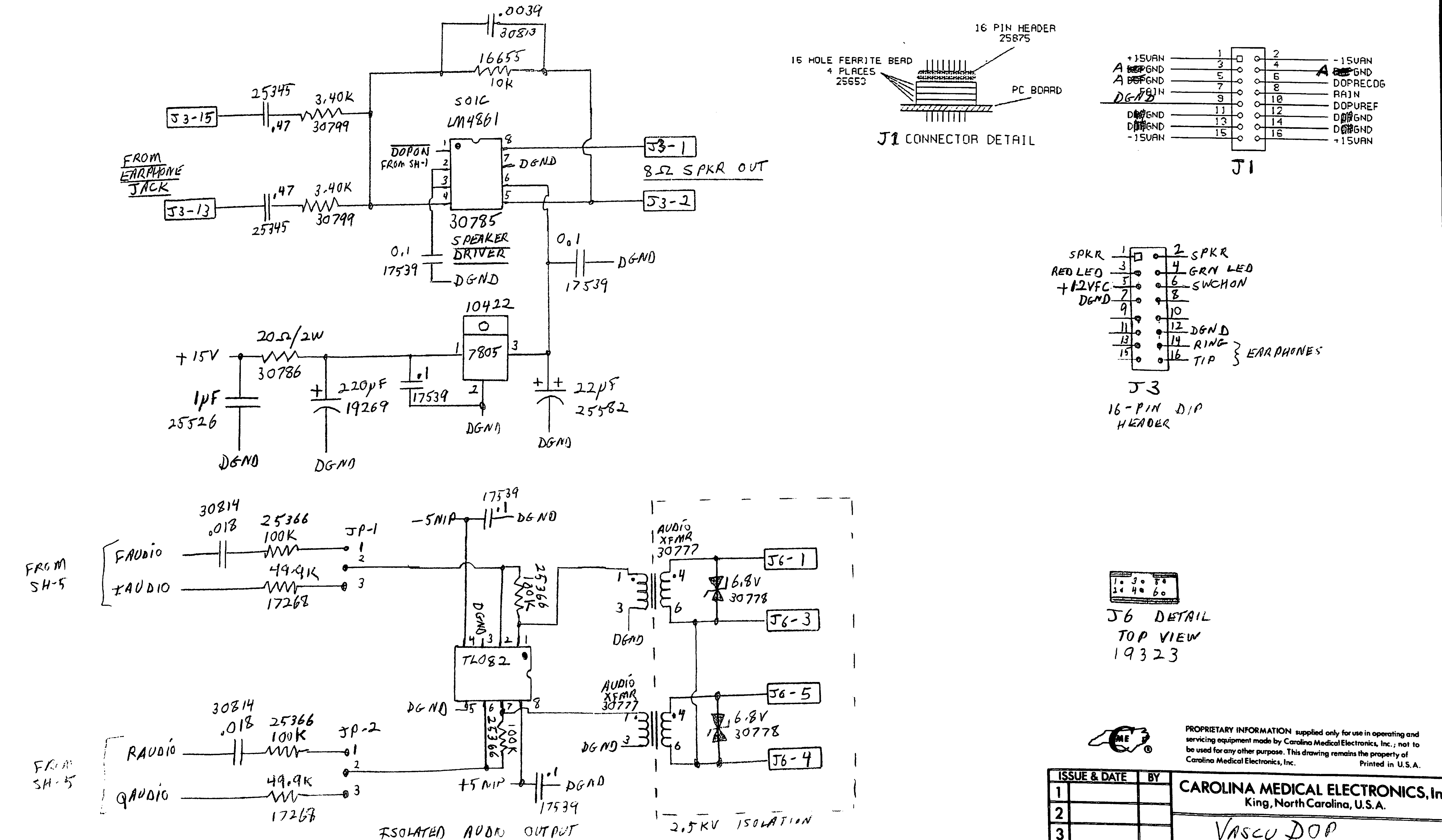
VASCU DOP
FREQ-TO-VOLTAGE CONVERTERS

SCALE
APP'D
NO. SC-30780 SH 6



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VASCU DOP
AUDIO OUTPUT & CONNECTORS

SCALE
APP'D
NO. SC-30780 SH 7