THE CARE AND FEEDING OF VACUUM TUBES

Now that the vacuum tube is being restored to its rightful place in the recording studio, I thought that it might be appropriate to review and renew some of the design and engineering features that should come in handy for the studio engineer. As the old adage says, "if you know how it works, it works." Along the way, I would like to dispel some of the myths that have grown up since the advent of the transistor. First, however, an overview of the history and operation of the vacuum tube might be in order. The first modern vacuum tube was invented over 100 years ago by Thomas Edison. In his effort to prolong the life of the filament of thelight bulb, he introduced a metal plate with a positive charge inside the glass envelope. He put a positive charge on this 'plate' (we still use the term today) and he noted that if you applied AC voltage between the filament (also still used today) and the plate, the AC would be rectified to DC, and so the rectifier tube was born. Incidentally, it didn't prolong filament life so he did no further research. In modern tube equipment, we still can use a rectifier tube in the power supply to convert the stepped up (through a power transformer) AC to DC voltages which are needed for the operation of tubes. Lee DeForest, just after the turn of this century, went back to Edison's design and added a screen (yes, just like a window screen) between the filament and the plate and the modern triode (three element) vacuum tube was born. This is how it works. The filament heats up to incandescence (but not nearly to the temperature of a light bulb) and begins to 'boil' off electrons. Electrons are negatively charged particles. By placing a positively charged plate nearby, in an evacuated envelope, (usually glass), the electrons will be attracted by the positive plate and current will flow. The reason for the vacuum is so the electrons don't bump into air (oxygen and nitrogen) atoms and lose energy. Also, the filament would burn out faster in the presence of oxygen. Now we have a flow of electricity through our diode (two elements). DeForest put a metal screen in the way of the electrons on their way to the plate and he found that by putting a very small voltage, we call it a 'signal' voltage on this screen, its small variations would be greatly magnified at the plate since this small voltage would control the flowof the electrons on their way to the plate. Hence, the signal would be amplified. Since there are three elements in this vacuum tube, it is called a 'triode.' The ability to amplify small signals into large signals was one of the most significant inventions of the 20th century. Its immediate application was to radio. Faint signals would be picked up by an antenna and then could be amplified up to whatever level you would want using one or more triodes. Using a diode tube, the galena (lead mineral) crystal and 'cat's whisker' detector then in use could be eliminated, giving a much more reliable circuit. In order to increase the 'gain' still more, additional vacuum tube stages could be added to the circuit after the rectifying

detector. In fact, tubes were often used to amplify the antenna signal, a radio frequency amplifier (RF) and then tubes could be used after the rectifier diode (detector stage) to amplify the audio frequency signal. The world suddenly became a much smaller place. News from around the globe, which formerly had to be routed through telegraph, telephone and underseas cables, could now be transmitted by radio from anywhere to anywhere. It didn't take long before the earth was encircled by amateur radio operators and almost immediately, some of these 'hams' began transmitting music, news and gossip. By the early '20's, Congress decided that commercial broadcasting should be controlled by the government (as it is in England) and legislation was proposed to do this. It was recognized for the potential for propoganda and it was thought that the government should be in charge of this. What changed this forever was a singer who failed to show up for her live concert at a radio station. The station owner put on a new record that he had just picked up at the record store to fill in. Within an hour, the record store was stormed by customers who bought out his entire inventory. That was the end of any thought of government control of radio. It had too big a commercial potential. President Franklin Roosevelt used radio most effectively in his addresses to the nation called 'Fireside Chats.' Hitler also used radio for propaganda most effectively. The design improvements of the vacuum tube continue. Additional elements were added to increase the amplification power of the tubes. Size was decreased so that the tubes would fit into smaller spaces, sometimes two or more tube were enclosed within the same envelope (whether made of glass or metal). A sleeve called a cathode was added around the filament which would emit electrons more effectively, and generally, the tubes became more rugged. Still, the basic triode principal has remained the same. How reliable are vacuum tubes? They are very reliable. When was the last time you had to replace the picture tube on your TV? When a tube is properly designed and built and it is functioning within its operating parameters, it can last for many decades of continuous use. Remember, the telephone repeater amplifiers on the trans-Atlantic telephone cables operating under the ocean have been there for a very long time. I just finished rebuilding a Theremin built by RCA in 1929. It still has the original tubes but if they had failed, I can still buy replacements. Tubes do not like mechanical vibration. Sitting in a guitar amplifier next to the speaker which is operating at high mechanical levels makes tube life short. The elements within the tube change distances from each other until they malfunction or short. Tubes do not like to be operated at their peak ratings. In consumer equipment, every ounce of gain is pumped out of the tube and this shortens tube life. The quality of tube manufacturing also varies widely. Although tube manufacturing stopped in this country a few decades ago, there are still a large number of these old

GE, RCA, Western Electric, Sylvania and other famous brands available, new in boxes (NIB). Availability of tubes is another myth. The U.S.S.R. never stopped making tubes. They were used extensively by the military. In the event of an atomic holocaust, tubes would not be wiped out whereas transistors would be destroyed by the radiation. Sources are plentiful. Old stock of good American tubes still exists and newly manufactured tubes are available from Russia, China and Hungary. Certain Western Electric tubes are now being manufactured again in America and the Japanese will soon re-enter the tube market. A word about prices and quality - foreign tubes are very inexpensive, as a rule. Old stock American tubes are getting rarer and therefore they are more expensive. Generally, in life, you get what you pay for. At the peak of American tube production, over 100,000 vacuum tubes were being manufactured A DAY. They were manufactured with tighter tolerances and with better materials and they are still superior to what is being made overseas. Go for the bucks. It makes a sonic difference. For certain very high gain and low signal requirements, such as in a tube mic or preamplifier, you might have to try a number of tubes to find one with the lowest noise. Tube noise is basically thermionic emission - the noise of the electrons hitting the plate. Why do vacuum tubes sound 'different' than transistors in audio applications? Russell Hamm and I published our research in the May 1973 issue of the Audio Engineering Society Journal. We had been curious for years about why transistors sounded so different. Our research, which is often quoted and mis-quoted, revealed some interesting facts. Attack transients (initial wave front information) from a good microphone can hit your mic pre-amp at plus 90 dB. The poor amplifier, whether tube or transistor, can pass about 40 dB. The rest is clipped. Clipping the excess 50 dB results in distortion. When we studied this distortion, we found that tubes would distort in even harmonics (mostly at the octave) and that transistors distorted producing odd harmonics, the 3rd and 13th partial predominating. You didn't have to be a pipe organ designer to know which distortion was more acceptable to the ear. Through the intervening years, many people have been trying, with varying success, to design transistor circuits that would sound like vacuum tubes. Finally, many manufacturers just went back to vacuum tube circuits. Another nice thing about tube electronics is that when over-driven (too much input signal on the screen grid), they go into distortion slowly, similar to the way the human ear goes into distortion. With transistors, no such luck. As with digital overload, you hear it instantly when you have gone too far. Trouble shooting with tubes is much simpler than with transistors. In all of my years of dealing with tubes, I have had a filament burn out only once. Generally, in time, a tube may become noisy. The first thing to do is to re-seat the tube in its socket. Wiggle it around a bit. A little dirt or oxidation can cause a lot of trouble which reseating or cleaning

with a little steel wool can fix. If this doesn't solve the problem, or if you are unsure of which tube is making the trouble, with a pencil eraser, gently tap the tubes. The ailing tube will generally get worse when you tap it. Sometimes, it will correct the problem. However, tubes plug into sockets so don't hesitate to replace the tube if you think that it is troublesome. Be careful - it may still be hot! It has taken a number of years for the recording industry to recognize the value of vacuum tubes. Many equipment manufacturers are again making very good vacuum tube equipment and 'vintage' equipment is fetching some very high prices. It is interesting to note that the advantage in some audio applications of vacuum tubes has never been lost. Guitarists and audiophiles have stayed with tubes. Transistors, indeed, have their place in the scheme of things; they make excellent switches, but for the 'warm', 'musical', 'live' sound and all the other descriptions verbalized about the quality of vacuum tubes, it is nice to see their resurgence in the audio industry. For me, they never left home. Walter Sear