BASIC DX TUTORIAL

Basic Harris DX Transmitter Tutorial

Basic DX Theory

The Harris DX Transmitters series, introduced in 1986, have proven to be the most efficient method of Amplitude Modulation at medium and long wave frequencies. The DX transmitters use solid state class D amplifiers utilizing MOSFET switching transistors, and through the design, power levels are almost unlimited.

The DX transmitters use many redundant class D, full-quad switching amplifiers that switch at the RF frequency. The quantity of amplifiers that are enabled at any moment depends on the carrier power and the modulating audio.

At unmodulated carrier there are a set number of amplifiers “enabled”. The same amplifiers stay enabled and are switching at the RF frequency. The number of modules enabled sets the peak-to-peak voltage of the carrier and is controlled by a DC component in the modulation section. This DC level is applied to an Analog-to-Digital converter and converted to a constant digital word. This word, through ROM chips enables a constant quantity of amplifiers resulting in carrier.

To modulate the transmitter, audio is added to this DC component resulting in a varying DC level that varies above and below the carrier DC at the audio rate. This is applied to the A/D converter that creates a digital word that varies higher and lower than the carrier word, again at the audio rate. This varying word, through the ROM chips, enables more and less RF amplifiers (at the audio rate) modulating the carrier.

The output voltage of all the RF amplifiers as collected in a series combiner pipe through the use of toroid transformers. Each enabled RF amplifier contributes an equal voltage step to the pipe. During modulation the peak-to-peak voltage is a constantly changing value due to the different quantity of RF amplifiers being enabled. This RF voltage goes through a band-pass filter and an impedance network to pass the carrier frequency at a 50 ohm output impedance.

Analog to Digital Conversion Process

In the Analog to Digital process, we will re-create the analog voltage represented by the digital word by turning ON or OFF units of RF voltage, holding them consistent for one time interval.

This process takes place in three steps: Divide the time into equal time intervals; sample and store the voltage amplitude at each time interval, then convert each recorded sample into a digital word.

The time scale uses the carrier frequency as the initial pulse. If the frequency is above 800 kHz then it is divided by two, giving a 1-2 uSec time pulse. If the carrier frequency is below 800, it is used to provide a 1.2-2.4 uSec pulse to clock the A/D chip.

The voltage at each timing interval, or every clock pulse, is sampled and recorded. Since the analog signal is constantly changing it would be impossible for the A/D converter to create a digital word that constantly changed in an analog fashion. Instead at every timing interval the signal is recorded and converted, much like a strobe light gives a small "picture" that changes in a jerky manner. However when the strobe light frequency is increased fast enough, the discrete steps are indistinguishable. Motion picture frames work much the same way. The analog signal is sampled and converted to a digital word at a very high rate.

This sampled voltage is sent to the A/D converter to create a 12 bit "word". The more bits used, the greater the resolution. With a 12 bit word there are 4096 different levels that can be created (2 to the 12 power). With a low level input analog voltage of 8 volts, the 12 bit word will change for every .0019 volt change at the input to the converter. The 12 bit word will change every 1.2 to 2.4 uSec, when the whole process will repeat itself.

This digital word will "enable" the corresponding amount of RF amplifiers which are also receiving a RF drive signal, changing the peak-to-peak voltage of the RF at the output of the transmitter. As you would expect, the output would not look smooth like an analog RF envelope, there will be "steps" every sample period. These steps will be filtered out in the band pass network since the square waves are rich in odd harmonics

Class "D" RF amplifiers

The MOSFET transistors used in the DX RF amplifiers are used simply as switches. In this discussion we will illustrate them as a switch (see Figure 1). With an ideal class D switch, all the power in a circuit is supplied to the load or output, and none wasted in the device. When the switch is open, no current will flow in the circuit, and no power to the load. When the switch is closed, full current flows through the circuit and the load, giving almost all the power to the load (when the MOSFET is conducting, the slight internal resistance does consume small amounts of power). Also, power is not delivered to the load is during the rise and fall time (switching) of the MOSFET.

When two such devices are placed in series with the output in the middle of them, we have what is called a half quad configuration (Figure 2). Each MOSFET is driven out of phase from each other, at the RF frequency, The output taken from their junction will be a square wave, switching between the DC voltage supply and ground.

When two half quads are joined we can double the peak-to-peak output. Figure 3 illustrates a full quad configuration. The output is still taken from the middle of each half quad, and applied to a transformer and DC blocking capacitor. The MOSFETs on each side are driven out of phase from each other, with S1 in phase with S4. This applies a potential from the supply on the transformer (+ to -). 180 degrees later S2 and S3 are conducting and applying a potential from the source on the transformer (- to +), the opposite or negative potential. The output of the full quad is then + to - the supply voltage. Remember that the switches are actually high speed MOSFETS that are switched in pairs at the RF frequency. Figure 4 is the Block Diagram of the RF Amplifier.

Series Combiner

Assuming that 1 Big Step Amplifier can generate approximately 1000 Watts, what would happen if another Amplifier is hooked to another primary of the same secondary? (See Figure 5). If you have one amp turned on, one off, you would be generating 1000 Watts. If you have both amps turned on, you would be generating 4000 Watts. With both amps turned off, you would be generating 0 Watts.

Each RF Amplifier is connected to a RF Voltage Transformer primary with a ferrite toroid coil. The turn ratio for all Big Step Amplifiers is the same (16:1). That is, there are 16 turns of wire on the toroid primary with a single turn (passing through the center of the toroid once) for each secondary. (See Figure 6).

When there are a low number of RF Amplifiers turned on, the rest of the Amplifiers, via their respective toroids, put a load on the combiner rod thereby decreasing the actual radiated power. Loading of the combiner also acts to protect the toroids and amplifiers (more on this later).

As more amplifiers are turned on, there are less amplifiers loading the system so the effective power delivered to the antenna per Amplifier increases. Since all of the Amplifiers are effectively connected to the same combiner rod (secondary), you can see that there would be quite a load when there are only a few amplifiers running/on.

The Series Combiner principle is used in two areas of the transmitter. These are in the Driver section and Binary/Big Step areas.

In the Binary Amplifier circuit the toroid turn ratio and the DC voltage source are changed to give the effective voltage on the combiner pipe fractional steps (as compared to the Big Steps). Depending on the transmitter, the Binary Amplifiers will be 1/2, 1/4, 1/8 1/16...of a Big Step voltage step. The smaller the transmitter, the more Binaries it will have. The Binary Amplifiers purpose is to help smooth out the transitions between the Big Steps (see Figures 7 & 8).

Block Diagram Description

In the block level description of a DX transmitter it should be noted that their are two main sections; RF Drive, and the Audio chain or Modulation section. Both of these sections come together at the RF Amplifiers. The RF Drive is consistent amplitude and always at all of the RF amplifiers. The Modulation section is the “enabling” of the RF amplifiers: When “enabled”, the RF amplifiers will produce the RF voltage at their output; when “disabled”, they will effectively be turned OFF with no RF output from that Module. Each RF amplifier has its own “enable” or control signal, and will be turned on independently from the other RF amplifiers depending on the modulation required. The Modulation of the transmitter takes place in the audio chain and does not affect the RF Drive section.

The Main Areas of the DX Transmitter are:

- Power Supplies
- RF Drive Chain
- Audio (Modulation chain)
- RF Amplifiers / Combiner
- Output Filters / Matching
- Control and Monitoring

See Figure 11, Overall Block Diagram.

Power Supplies

The High Voltage Supply produces the +230V, +115V and +60V that are used by the RF Amplifiers, RF Drivers and Pre-Driver.

The Low Voltage Supply provides the +/- 22V and the +/- 8V. These voltages are used by the rest of the circuitry in the transmitter. These areas are:

- Oscillator
- Buffer Amplifier
- Audio Input
- A/D Converter
- Controller
- Output Monitor
- External Interface

RF Drive

The RF drive chain includes the Oscillator through the Power Amplifiers. This section generates a RF signal then amplifies it to a level high enough to provide drive for the Power Amplifier stage.

The RF Signal path begins at the Oscillator printed circuit board with the crystal oscillator circuit, or it can be brought in to the transmitter from an external source. The most common uses of the external input are AM Stereo operation, multiple transmitter operation, or for utilizing a Frequency Synthesizer. Another use could be for emergency operation after a crystal failure.

A plug-in Buffer Amplifier module amplifies the Oscillator output from a TTL level to approximately 20 V p-p. This level provides a stable input to the next stage, the Predriver.

The predriver stage is the first use of one of the identical and interchangeable RF Amplifiers used in the DX transmitter. The Predriver amplifies the Buffer Amplifier signal to a high enough level to operate the modules used in the RF Driver.

The RF Driver consists of (in most transmitters) 3 or more of the RF Amplifiers. Some of the RF Drivers are “frequency determined”, some are always on, others are operated in a “reserve capacity”, to act as RF Drive level AGC.

The outputs of the RF Driver Amplifier modules are combined in the Driver Combiner, outputting to the RF Splitter input. The RF Splitter provides 2 identical RF Drive signals to each of the RF Amplifiers.

The RF Amplifier stage consists of many redundant plug-in modules. The “Digital Amplitude Modulation” encoded audio signals from the Modulation Encoder turn on as many RF modules as required at any instant. The method of digital modulation employed in the transmitter uses a combination of whole steps (Big Steps) and fractional steps, referred to as “Binary Steps”.

The Main Combiners and one Binary Combiner make up the PA Combiner. The total modulated RF output is fed to the Output Network.

Audio Input and Modulation Section

The modulation section of the transmitter accepts an analog input signal and converts it to a digital signal. The digital signal is then processed or “encoded” to control the turn-on and turn-off of the RF Amplifiers, producing the digital amplitude modulation or “Quantized Amplitude Modulation”. Printed circuit boards in the modulation section include the Analog Input (Audio Input) Board, Analog to Digital Converter Board, Modulation Encoder Boards and the DC Regulator Board.

Audio is fed into the Analog Input Board where it is processed and manipulated. This processing includes “rolling-off” the high audio frequencies for AM Band channel spacing, i.e. 10 kHz or 9 kHz, and adding a DC component to control or determine the unmodulated carrier power. The (Audio + DC) signal is sent to the A/D Converter. A second (Audio + DC) signal is sent to the DC Regulator.

The A/D (Analog to Digital) Converter board converts the (Audio + DC) signal into a 12 bit digital audio signal. The (Audio + DC) signal is sampled about once every 1.2 to 2.5 microseconds, at a rate determined by the operating frequency of the transmitter:

530 - 800 kHz - Sample Frequency = Transmitter Frequency

800 - 1610 kHz - Sample Frequency = Transmitter Frequency / 2

The Modulation Encoders convert the 12 bit digital audio information into control signals, turning the individual RF Power Amplifier modules on or off as required by the transmitter power level and the instantaneous modulation level. Also, whenever a high VSWR condition is detected, a PA KILL signal is sent from the Output Monitor Board directly to the Modulation Encoders. This signal will cause the Modulation Encoders to turn off ALL RF Amplifier stages within a few microseconds of detection of the VSWR fault.

The DC Regulator produces the B+ (+5 VDC) and B- voltages used by the Modulation Encoders. The (Audio + DC) sample from the Analog Input Board “modulates” the DC Regulator “B-” output voltage. The Modulated B- is a bias voltage for the RF amplifier modules in the Power Amplifier stage which varies the turn on/turn off times of the modules to optimize distortion and noise performance.

RF Amplifiers

The RF Amplifiers use MOSFET transistors in a full quad configuration, switching class D. Their output will be switching from +Vcc to -Vcc when enabled. All of the RF amplifiers are identical, as are the Big Step RF voltage steps at the combiner pipe.

RF Drive is always applied to all of the RF amplifiers. When the module is enabled, it is allowed to switch on in the full quad configuration. When they are disabled or turned OFF, the RF drive to the lower MOSFETS is shorted to ground, see Figure 4. This effectively reduces their output to zero since the toroid transformer (output of the module) has no ground reference for the +Vcc. The upper MOSFETS will still receive RF drive to satisfy any induced RF energy into the toroid from other Amplifiers that are enabled, so there is no open winding of a transformer.

Output Filters/Matching

The RF Amplifier outputs are combined and go through a Bandpass / Output Network to a 50 Ohm RF Output point. A Pi Matcher is a tunable matching device for antenna loads that are not exactly 50 Ohms.

The Output Network transforms the low impedance of the PA Combiner output to 50 Ohms. This is done in two basic sections, the Bandpass Filter and the PI Matching Stage. The Band Pass Filter also serves to filter out the odd harmonics of the square waves produced by the RF amplifiers. The Output Network also includes the Output Monitor circuitry which provides the RF Amplifiers protection against high VSWR conditions.

Control and Monitoring

Three RF Status indicators on the transmitter status panel indicate Oscillator, Buffer Amplifier and Predriver status. Indicators are also present for RF Underdrive and RF Overdrive conditions; these faults will turn off the transmitter. One or more of these indications can quickly direct you to the faulty section if you fully understand exactly what the indicators monitor and what they don’t. The RF Sense outputs go to circuits in the Controller which operate the RF Indicators.

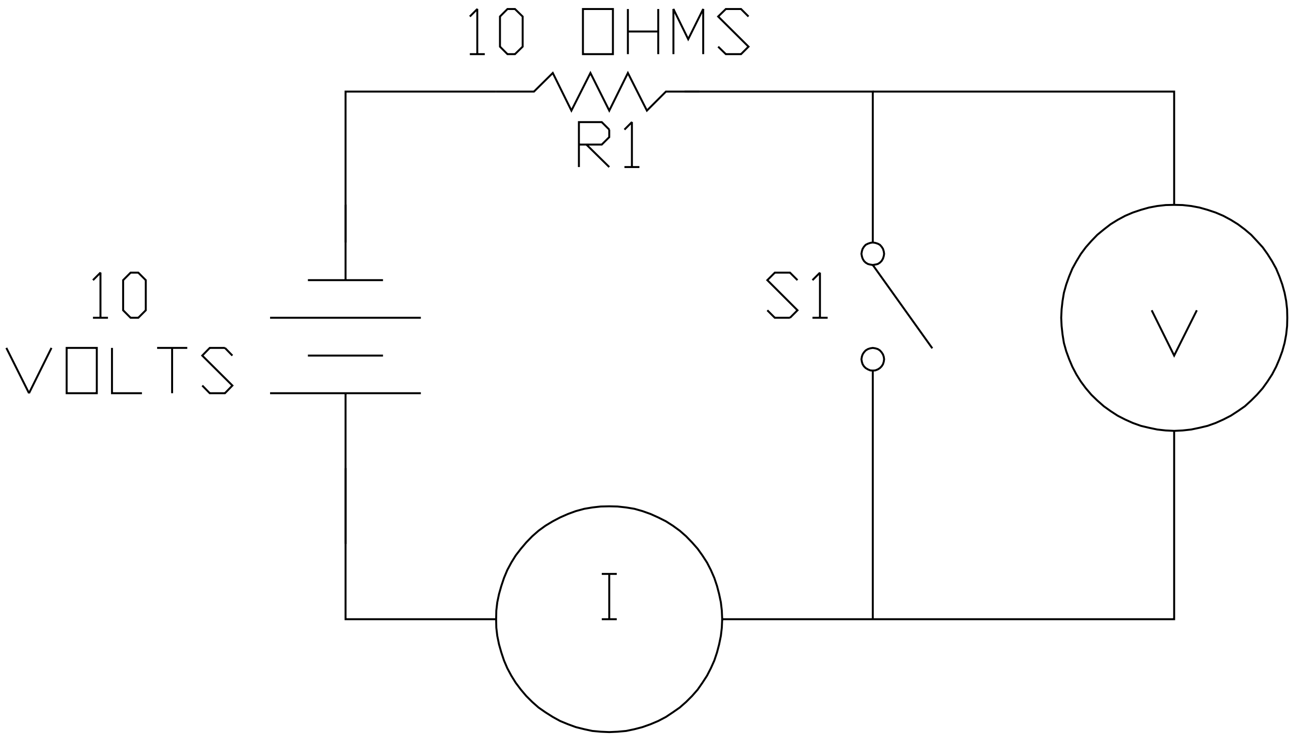
The status panel indicators are normally green, and will turn red (or orange) when a fault or abnormal condition exists. When the transmitters are off, and no RF is present to be detected, you would expect the RF Sense circuitry for the Oscillator, Buffer and Predriver to indicate a fault. However, since this is a normal condition, the alarm indications are held green (disabled) until the PA Supplies are energized.

Additional indicators are located on the Modulation Encoders and RF Amplifiers; each RF Amplifier module has fuses and fuse indicators. If an amplifier fault causes a fuse to open, a red LED will illuminate on the RF amplifier as well as the Modulation Encoder that serves that amplifier indicating the location of the open fuse.

The Controller section consists of the Controller, LED Board, External Interface, and the Switch Board/Meter Panel. The PA Turn-On/Turn-Off command is recognized by the Controller from any of the LOW, MED, HIGH, or OFF buttons on the Switch Board, or from external inputs. Circuits on the Controller energize the main contactors for the PA Power Supply, and provide carrier power control.

The LED Board contains fault and overload sensing and logic. It provides LED ColorStatÔ panel indications to monitor transmitter operation. These status indications are also available as remote status outputs from the External Interface. Many status indications are “latched” to provide fault indications until they are “reset”, even if the transmitter is turned OFF. A battery backup supply holds status indications in memory if AC power fails or is turned off. The backup supply also enables the transmitter to automatically restart when AC power is restored.

Using Quantized Amplitude Modulation through solid state power amplification, the DX series transmitters are field proven, highly efficient means of transmission. The simple design, efficiency, and robust output combine unsurpassed audio quality and ease of use with low cost operation.



S1	I	V	PWR R1
OPEN	0A	10V	0 W
CLOSED	1A	0V	10 W

4316-023.dwg

Figure 1
MOSFET Switch States

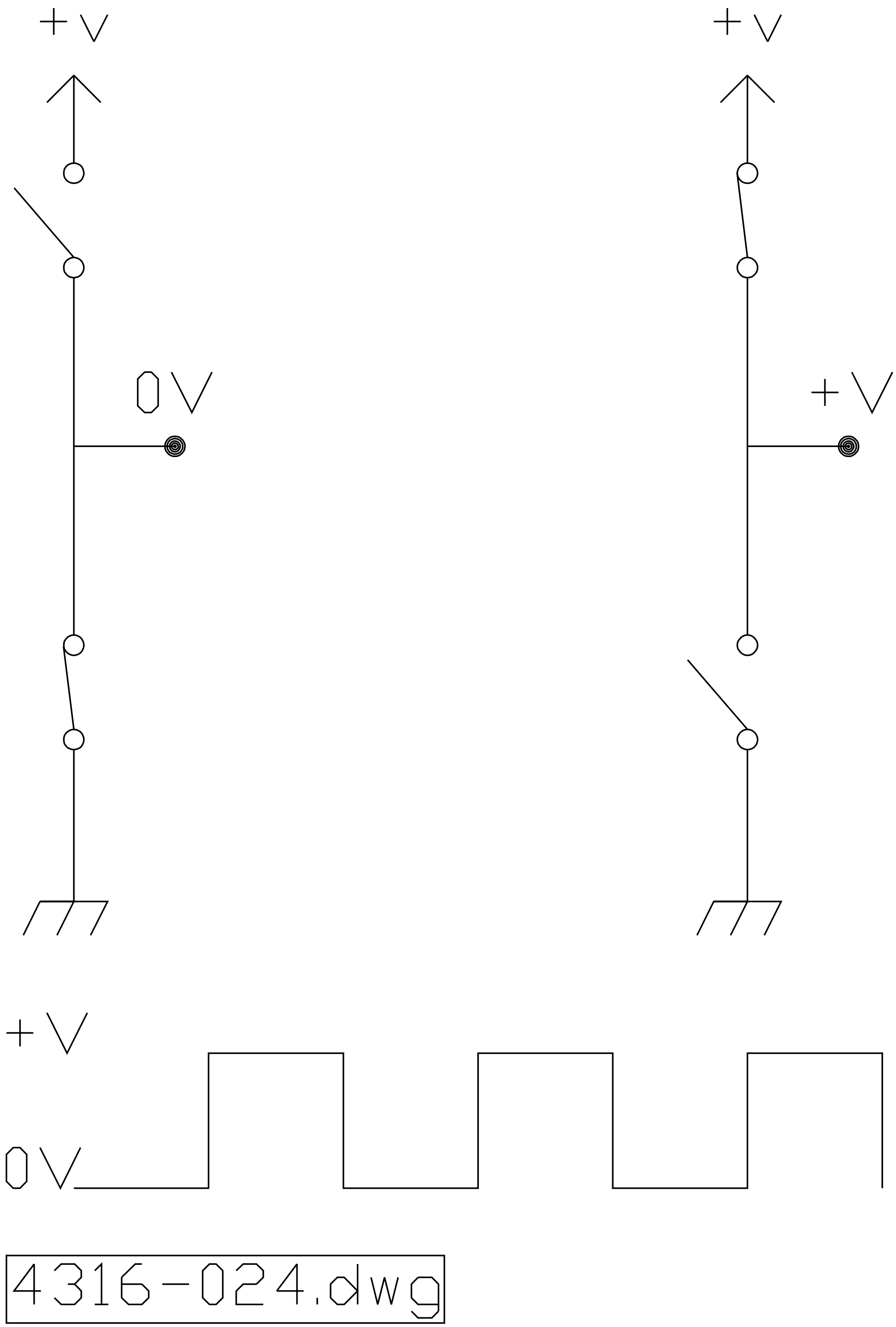


Figure 2
"½ Quad" Example

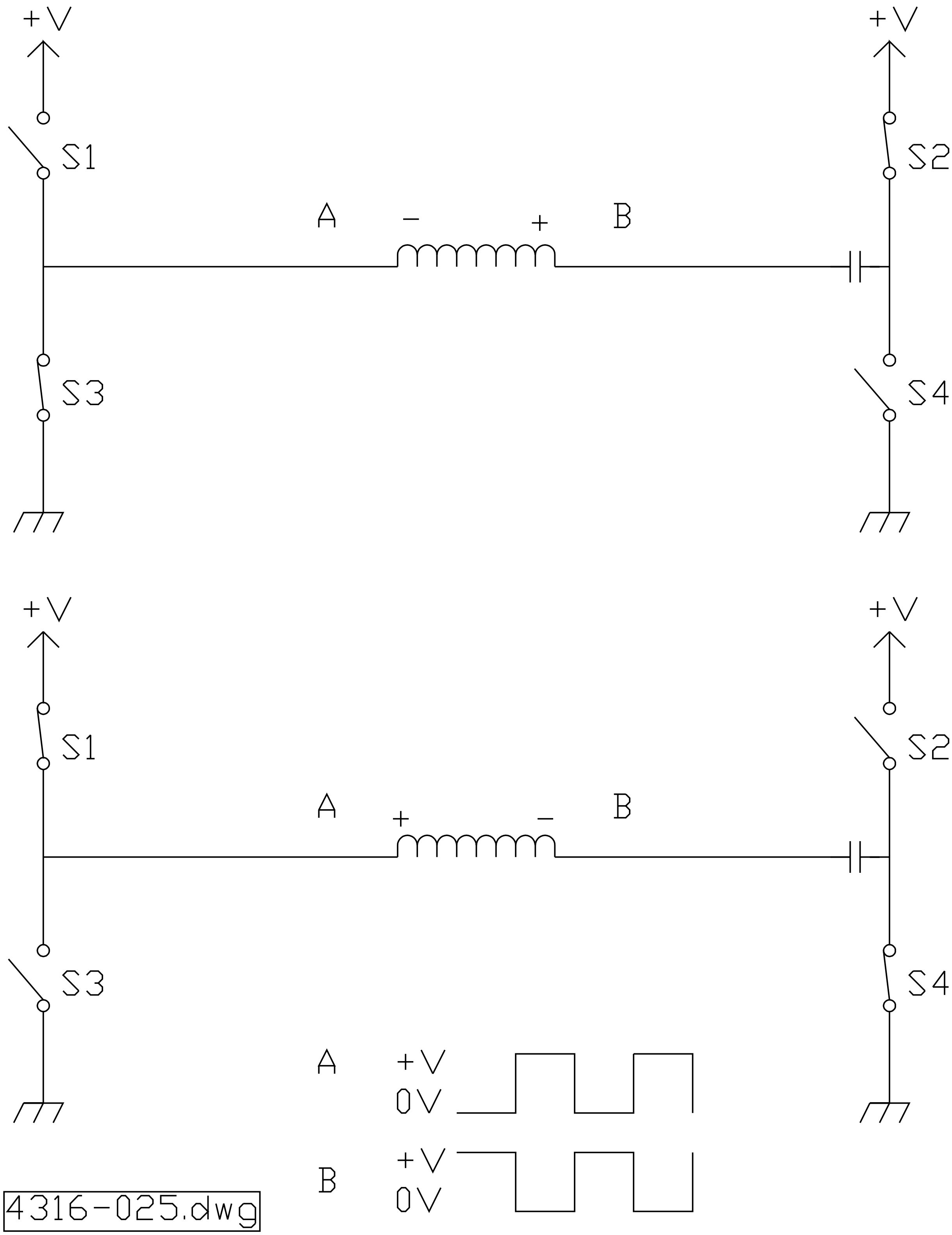


Figure 3
"Full Quad" Example

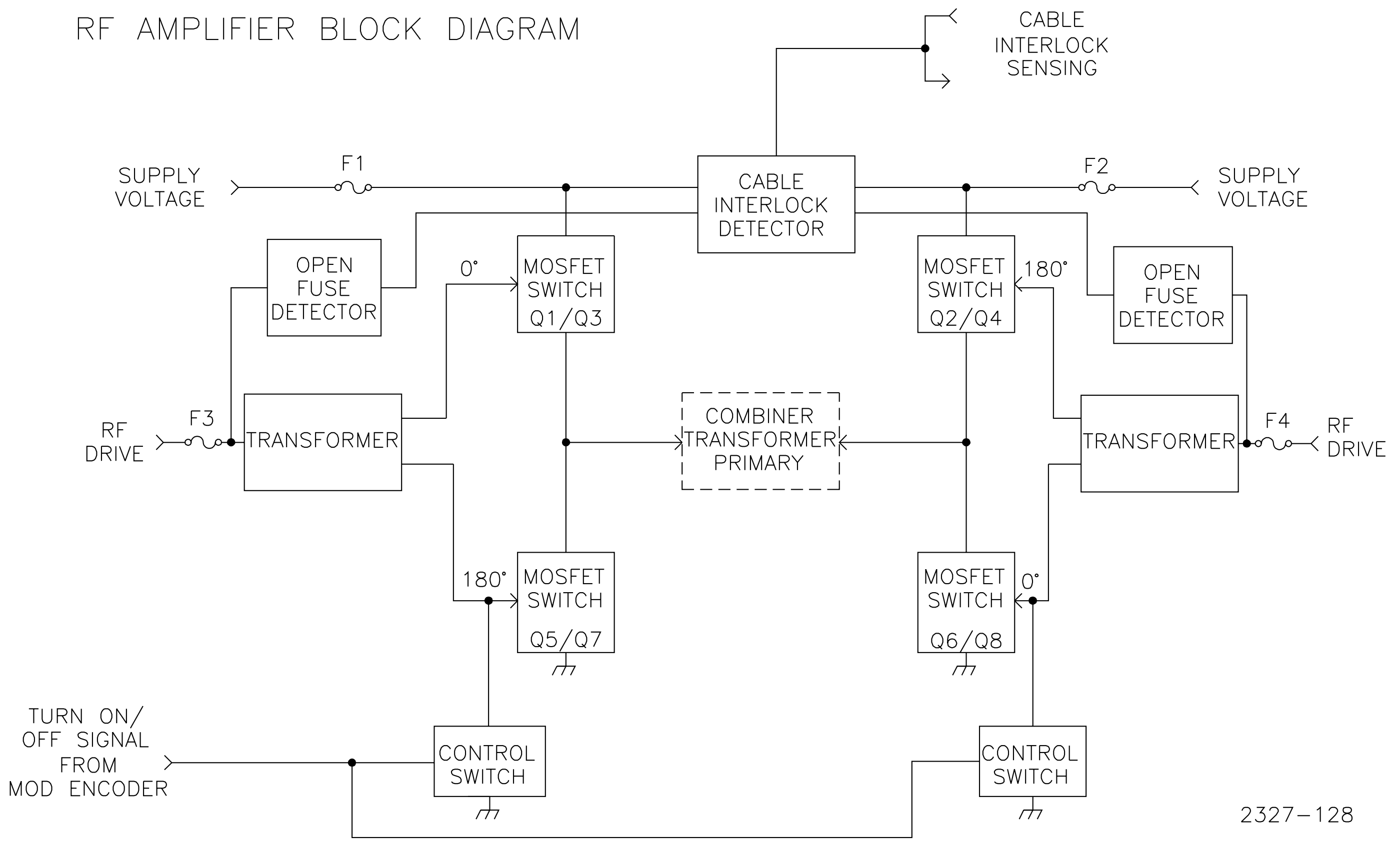


Figure 4
RF Amplifier Block Diagram

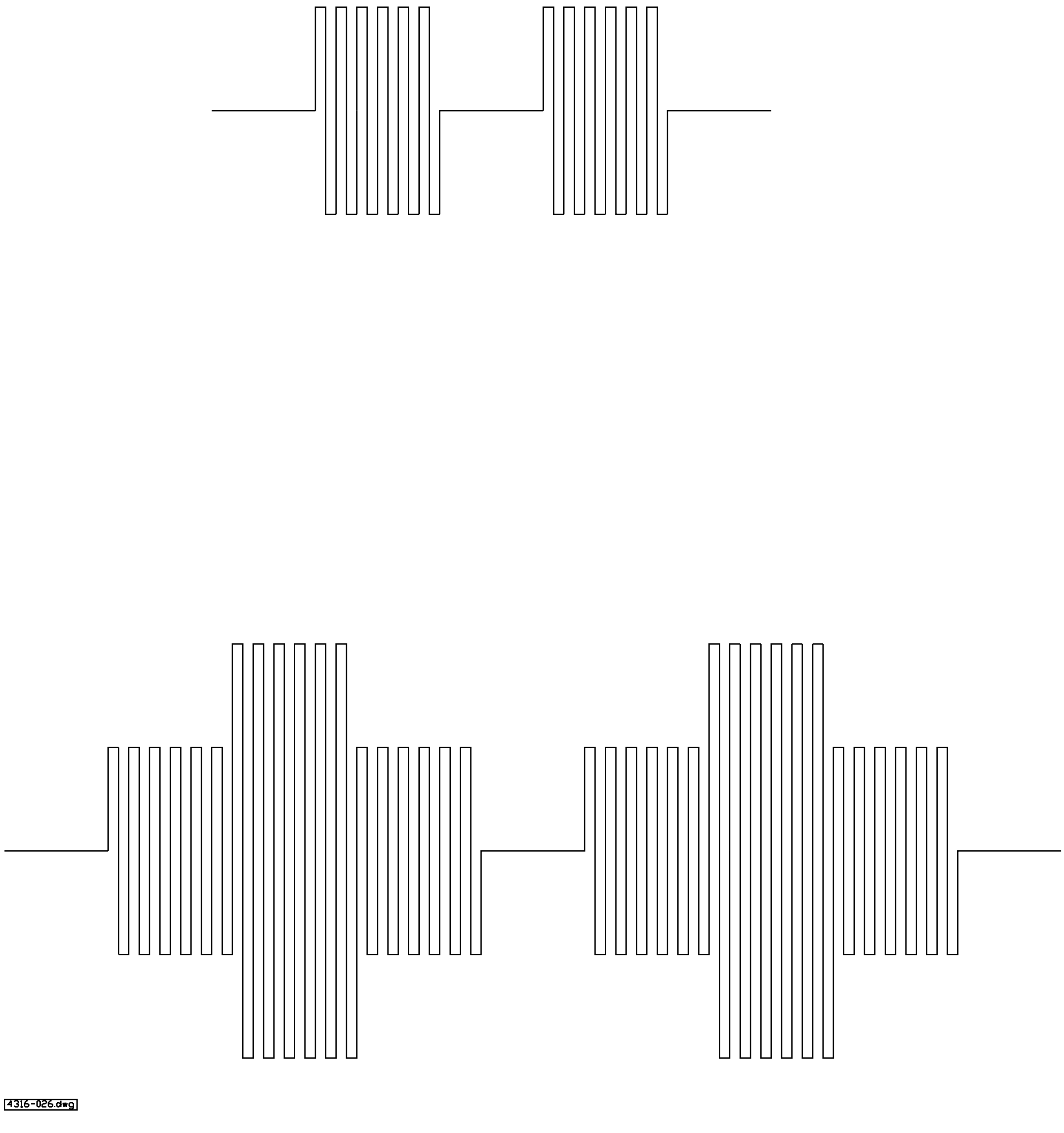


Figure 5
Combiner RF Addition

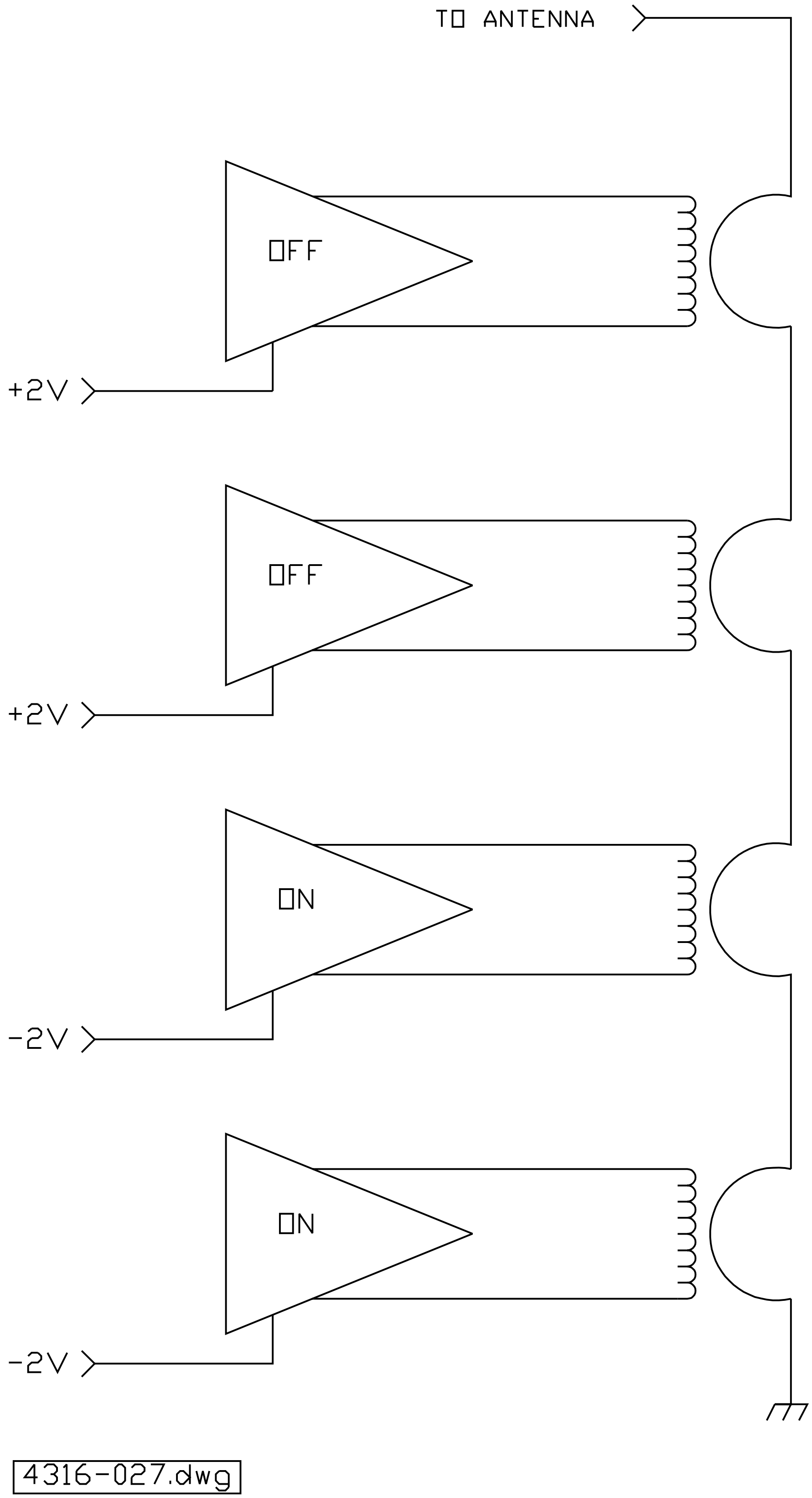


Figure 6
Multiple RF Amps

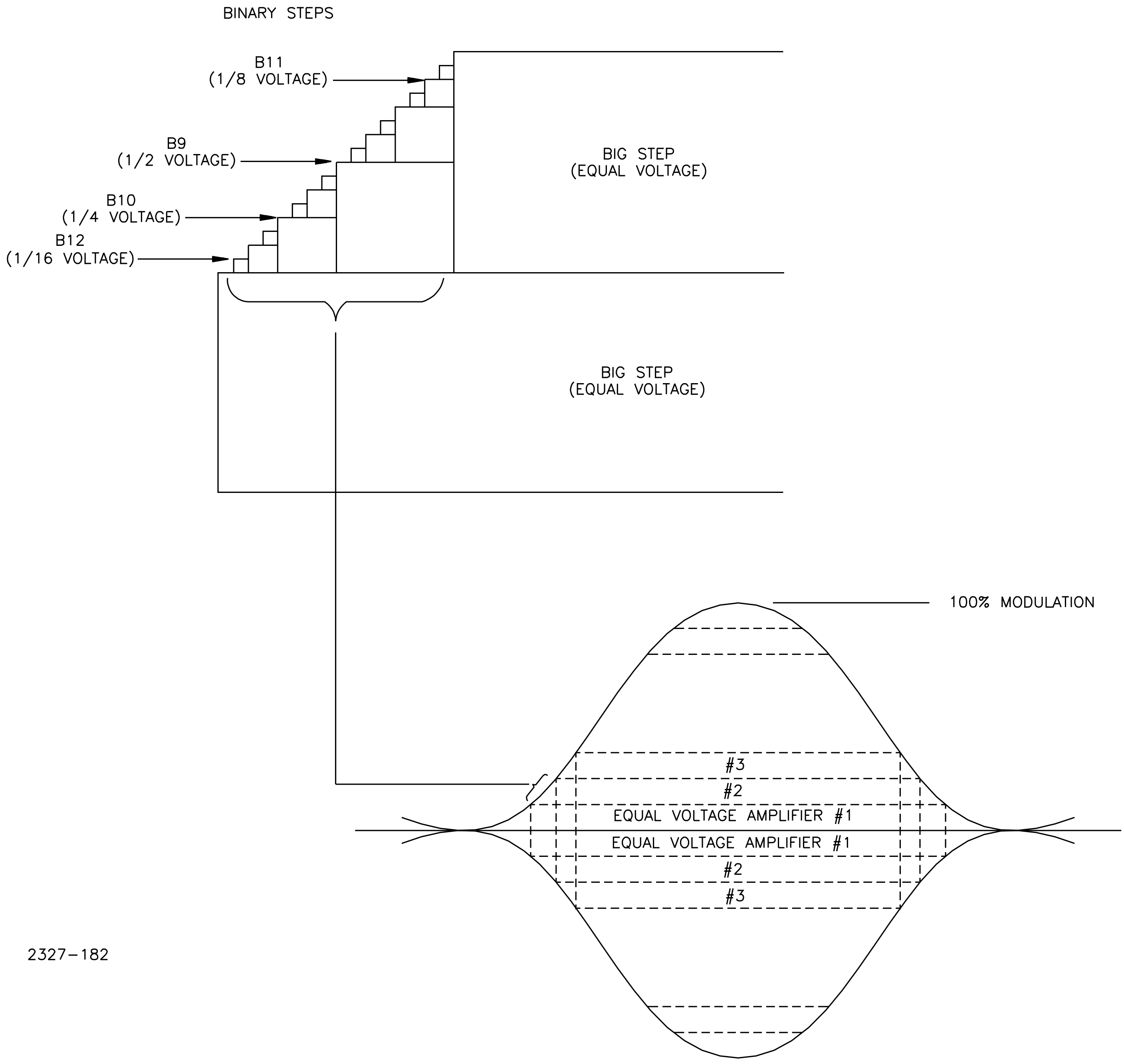


Figure 7
Digital AM Modulation

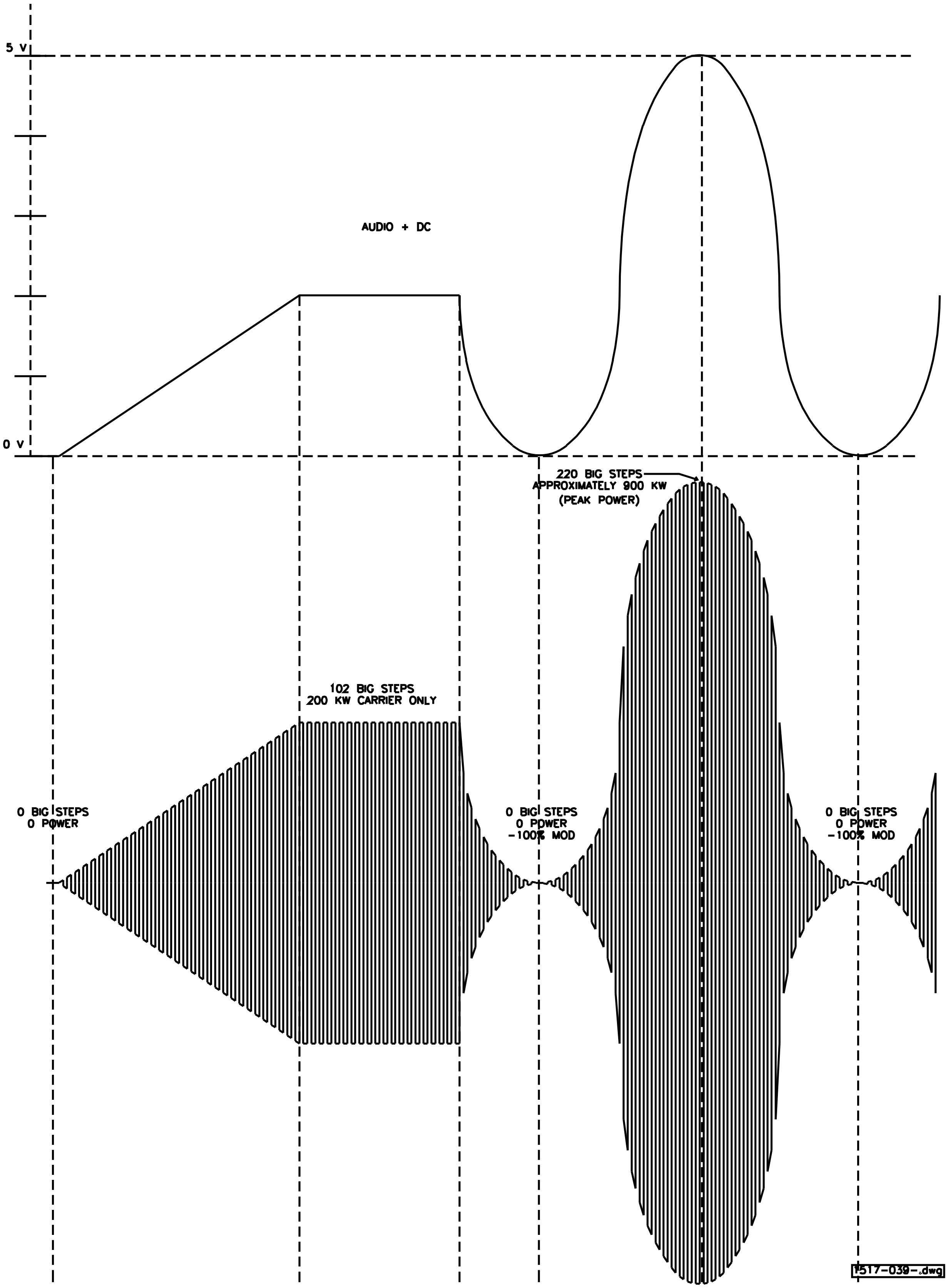


Figure 8
Audio Modulation

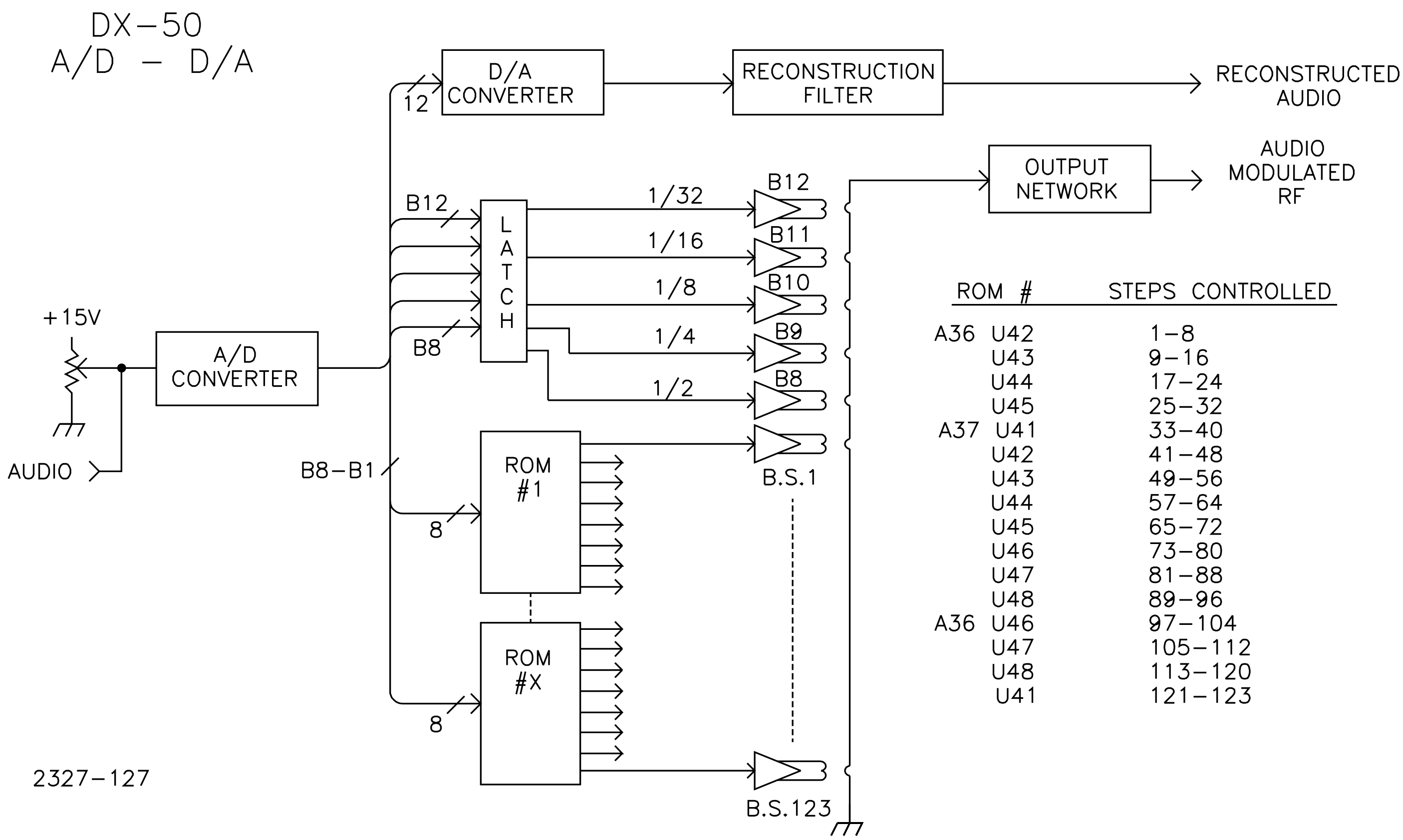


Figure 9
A/D - D/A

Voltage (in mV)	12bit Dec. equiv.	12 bit Digital Word (Split in Half: 6 - 6)	6-6bit Dec. equiv.	Amps ON	1 = ON 0 = OFF Binary Amps (Direct)						~	1 = ON 0 = OFF Big Step Amps 1-8 (Via ROM U45)								~	1 = ON 0 = OFF Big Step Amps 17-24 (Via ROM U46)								~	1 = ON 0 = OFF Big Step Amps 33-40 (Via ROM U42)							
		MSB LSB			B7 1/2	B8 1/4	B9 1/8	B10 1/16	B11 1/32	B12 1/64	~	1	2	3	4	5	6	7	8	~	17	18	19	20	21	22	23	24	~	33	34	35	36	37	38	39	40
1.82	1	000000-000001	0-1	1/64	0	0	0	0	0	1		0	0	0	0	0	0	0	0		0	0	0	0	0	0	0	0		0	0	0	0	0	0	0	0
3.64	2	000000-000010	0-2	2/64	0	0	0	0	1	0		0	0	0	0	0	0	0	0		0	0	0	0	0	0	0	0		0	0	0	0	0	0	0	0
63.7	35	000000-100011	0-35	35/64	1	0	0	0	1	1		0	0	0	0	0	0	0	0		0	0	0	0	0	0	0	0		0	0	0	0	0	0	0	0
114.66	63	000000-111111	0-63	63/64	1	1	1	1	1	1		0	0	0	0	0	0	0	0		0	0	0	0	0	0	0	0		0	0	0	0	0	0	0	0
116.48	64	000001-000000	1-00	1 0/64	0	0	0	0	0	0		1	0	0	0	0	0	0	0		0	0	0	0	0	0	0	0		0	0	0	0	0	0	0	0
138.32	76	000001-001100	1-12	1 12/64	0	0	1	1	0	0		1	0	0	0	0	0	0	0		0	0	0	0	0	0	0	0		0	0	0	0	0	0	0	0
944.58	519	001000-000111	8-07	8 7/64	0	0	0	1	1	1		1	1	1	1	1	1	1	1		0	0	0	0	0	0	0	0		0	0	0	0	0	0	0	0
1,474.20	810	010001-101010	17-42	17 42/64	1	0	1	0	1	0		1	1	1	1	1	1	1	1		1	0	0	0	0	0	0	0		0	0	0	0	0	0	0	0
1,476.02	811	010001-101011	17-43	17 43/64	1	0	1	0	1	1		1	1	1	1	1	1	1	1		1	0	0	0	0	0	0	0		0	0	0	0	0	0	0	0
2793.70	1535	010111-111111	23-63	23 63/64	1	1	1	1	1	1		1	1	1	1	1	1	1	1		1	1	1	1	1	1	1	0		0	0	0	0	0	0	0	0
2795.52	1536	011000-000000	24-00	24 0/64	0	0	0	0	0	0		1	1	1	1	1	1	1	1		1	1	1	1	1	1	1	1		0	0	0	0	0	0	0	0
4,961.32	2726	101010-100110	42-38	42 38/64	1	0	0	1	1	0		1	1	1	1	1	1	1	1		1	1	1	1	1	1	1	1		1	1	1	1	1	1	1	1
5,000.68	2751	101010-111111	42-63	42 63/64	1	1	1	1	1	1		1	1	1	1	1	1	1	1		1	1	1	1	1	1	1	1		1	1	1	1	1	1	1	1

NOTE: The decimal equivalent of the first "half" (6 MSBs) of digital word is number of RF Amps turned on (via Modulation Encoders ROM).
The decimal equivalent of the 2nd "half" (6 LSBs) of digital word is the numerator (over 64) fractional value equivalent of 1 RF Amp's total (direct).
For 2nd half (6 LSBs) of digital word: Each bit directly controls (enable = 1 / disable = 0) one binary amp.
To turn on all Amps = 42 63/64 = 101010111111 = 2751 discrete sampling levels (4096 possible - not all used).
5 volts divided by 2751 = 1.82mV = Resolution level (One bit change with 1.82 mV change).
Voltage values are theoretical and for reference only.

Figure 10
DX ROM Encoding Table

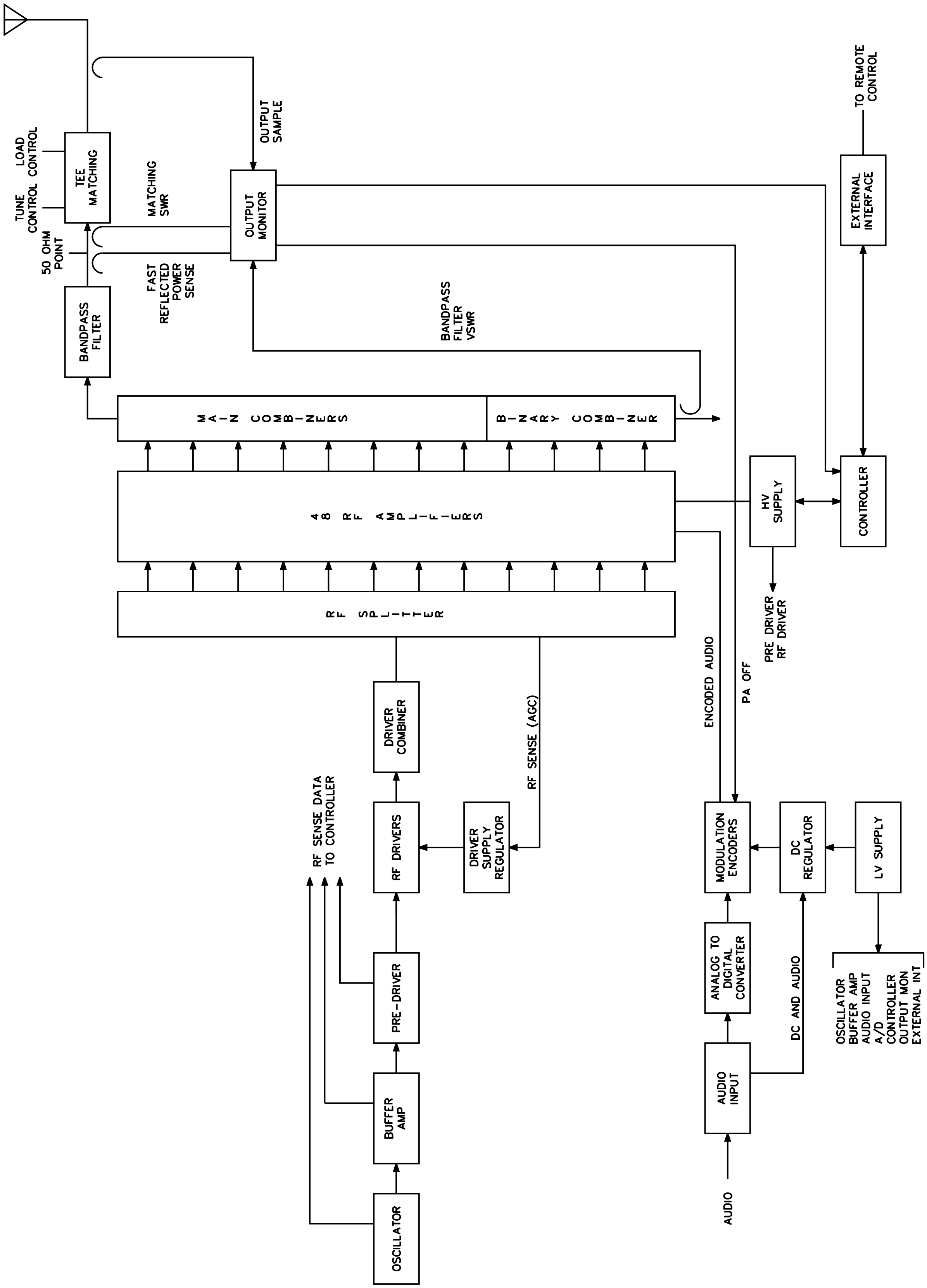


Figure 11
DX-10 Block Diagram