CANAC

Product Design

CANAC Radio Transmitter 450 MHz

User and Operation Manual

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Revision History

Date	Revision	Description	Signature / Date	
10/13/99	A	Initial DRAFT	Prepared	Francois Methot
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mm/dd/yy			Prepared	
			Verified	
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mm/dd/yy			Prepared	
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			Approved	
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Technical Description

The present document describes each functional block of the radio. The information regarding calculations of the detailed design; PLL loop filter, impedance matching, VCO tank circuit etc. are described in the DESIGN DETAIL of the RF Radio and is available upon request. The module contains only a transmitter but the hardware is ready to install a future receiver.

1.0 Context of Operation:

The purpose of this radio is to enable the locomotive engineer to remotely control the locomotive in the yard. The locomotive engineer is equipped with an *operator control unit* (OCU) and communicates with the locomotive directly or via a *repeater unit* (RPU) that is well located within the yard (figure 1).

The overall system must support many operators on the same frequency with different time slots (TDMA) in half duplex. The frequencies used are between 450-470 MHz . The radio transmits at 19.2 Kbaud in a 25 KHz (or 9.6 Kbaud in a 12.5 KHz or 4.8 Kbaud in a 6.25 KHz) channel spacing at a maximum power of 1 Watt.

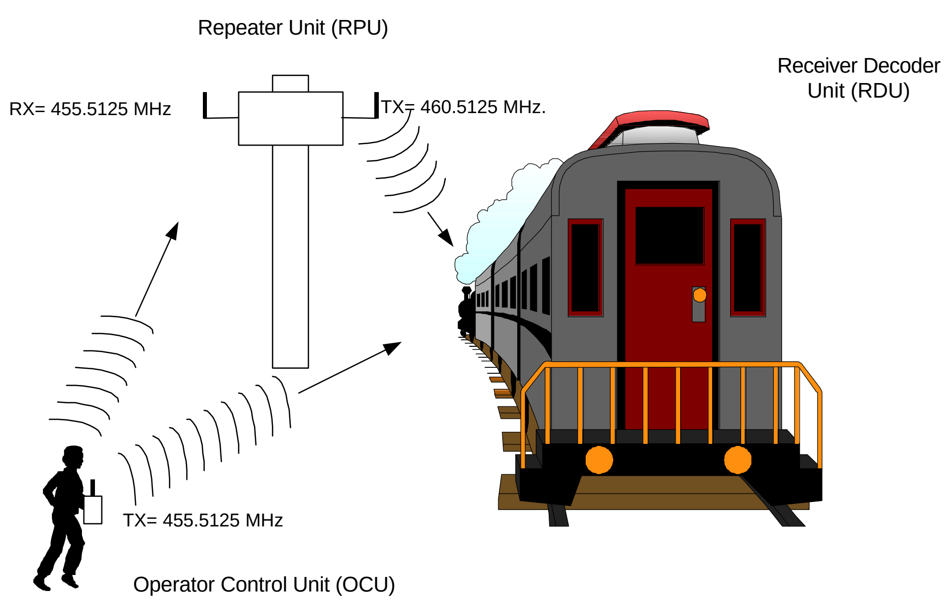
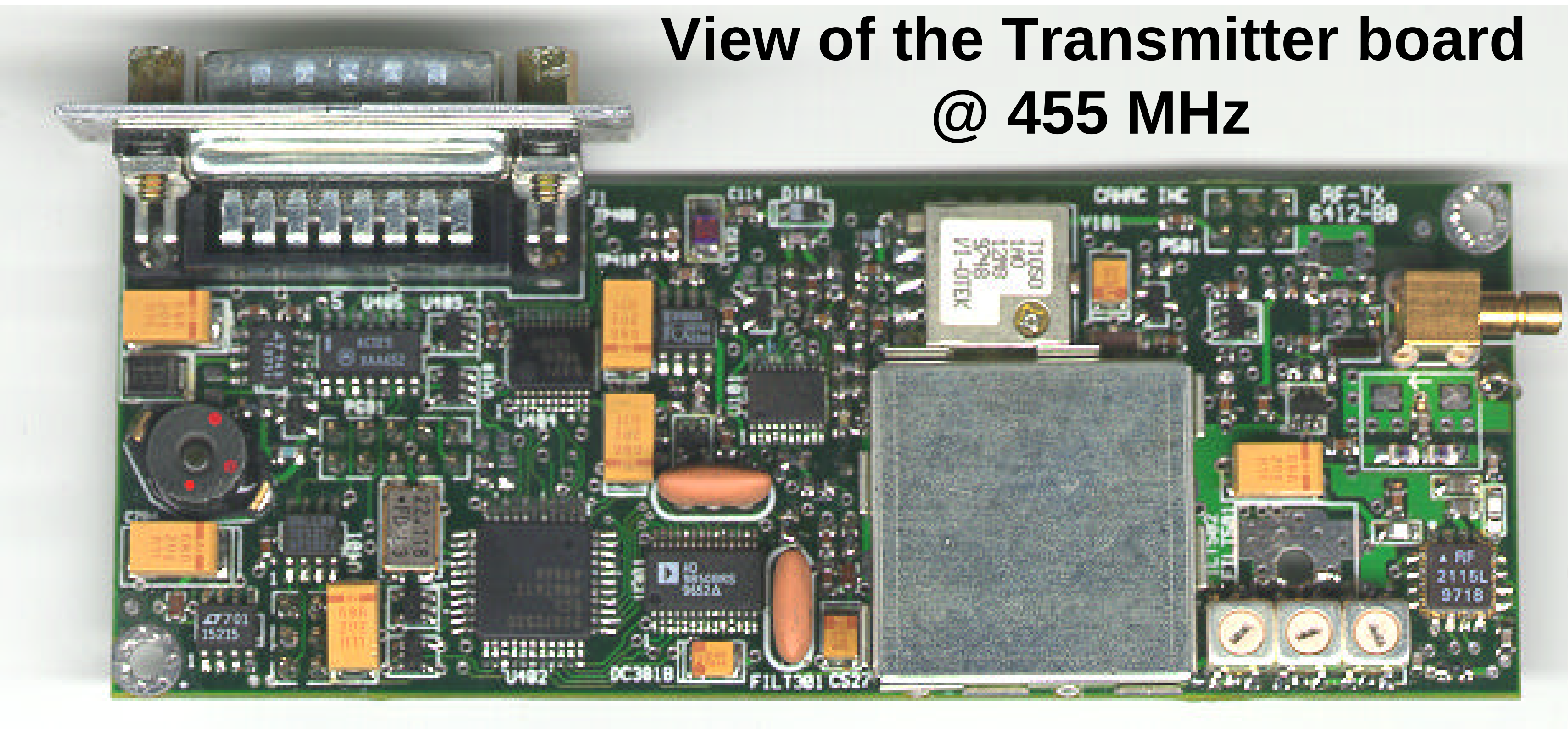


Figure 1



View of the Transmitter board @ 455 MHz

Block Diagram of the Transmitter

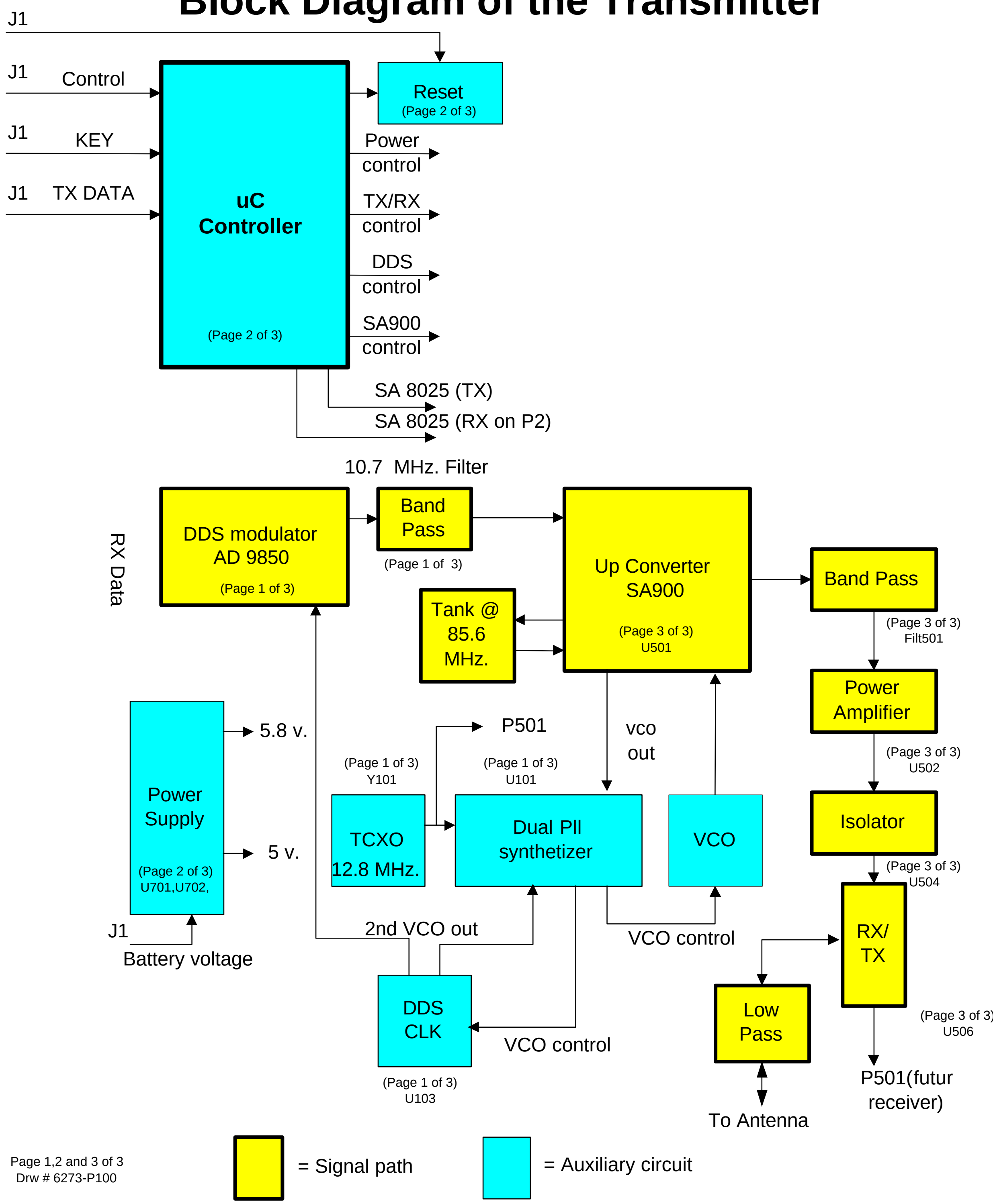


Figure 3

2.0 General Design Overview

2.1 3FSK Partial Response Modulator

The core of the 3FSK modulator is completely digital by means of a direct digital synthesizer (DDS). The DDS (U301) requires a clock much higher than the actual output frequency to facilitate the analogue reconstruction of the desired signal with a DAC. In the present design, the DDS clock is provided by the auxiliary VCO, which is 25.6 MHz (locked on the temperature compensated crystal oscillator TCXO). This signal is converted into CMOS level by a HC04 single gate inverter (U103).

To minimize DC power and spurious level, the DDS will synthesise a low frequency FM signal at 10.7 MHz and then be multiplied by a factor of 8 by means of a phase lock loop (PLL) at 85.6 MHz (TXIF) and finally be converted to the desired RF frequency with a frequency up-converter (U501). The FM signal at 10.7 MHz must be modulated with a modulation index 8 times smaller because of the multiplication factor of the PLL at 85.6 MHz.

Figure 4 illustrates the process of the generation of the 3FSK signal.

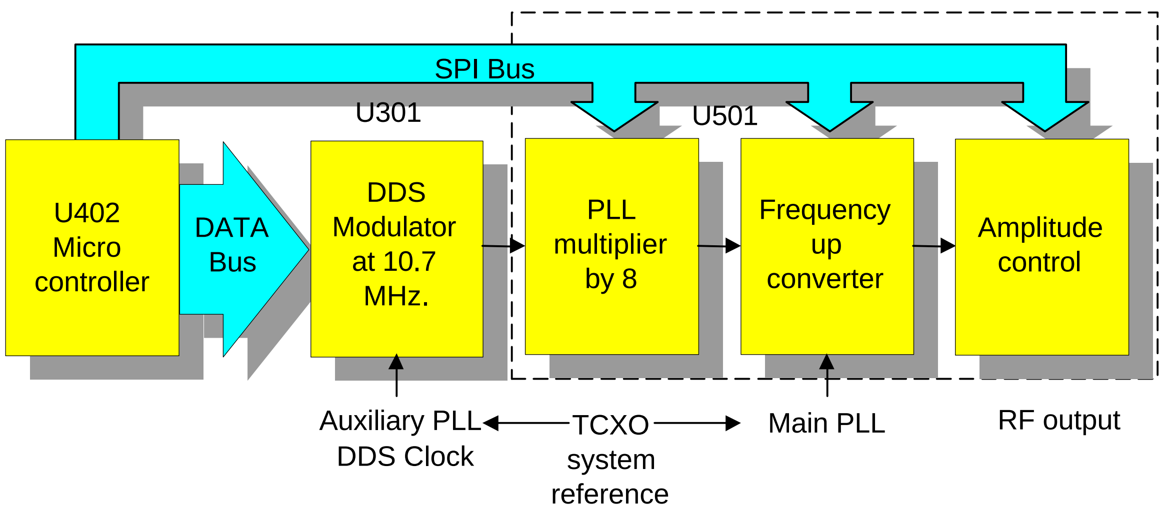


Figure 4

The micro controller receives the DATA to be transmitted by TXDATA at J1 and follows this information to the RX port of the micro controller via U404. The information is stored in RAM. The program starts a routine to initialise the transmitter with the proper sequence for the power up. After the power up, the micro controller starts the DDS to generate the FM signal. The algorithms to generate the FM signal incorporate the data filtering as follows:

1. At the beginning of each transmission, the DDS generates a preamble that consists of the center frequency F0 for a duration of five bits time plus 3 bits time. During the first five bits, the RF pulse shaping to control spurious due to turn on takes place. During that time, the power amplifier reaches the maximum power as a sine shape at each T/4, where T is the bit time, over the first five bits (see figure 11). Then the transmission starts with three bits of center frequency. These three bits are used on the receiver side for carrier detection and to prepare the clamp circuit (dc offset of the data signal).

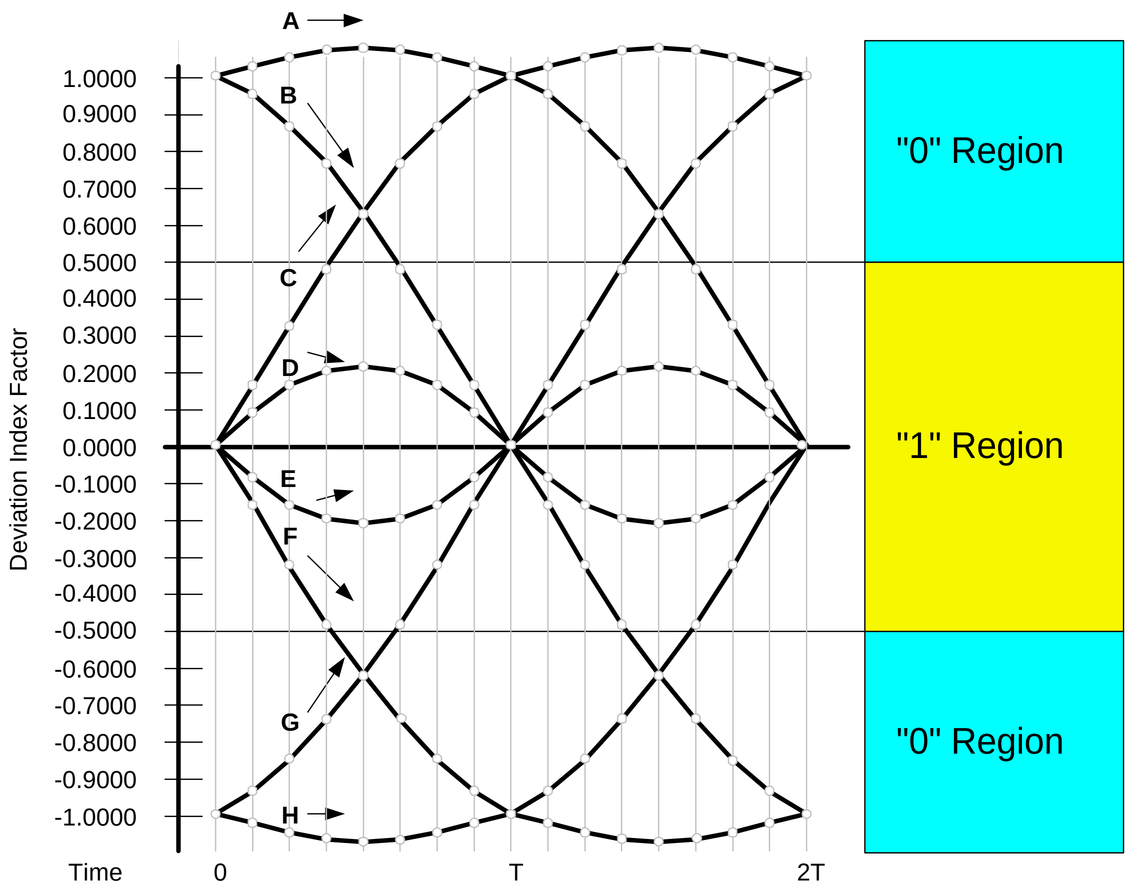
2. The carrier is then frequency modulated in relation to the DATA level and the two previous bits. For a binary level "0", the DDS generates frequencies that correspond to trajectories H, D, F and B functions of the two previous bits (see figure 5). Intermediate frequencies are generated to reach the frequency at each T/4.

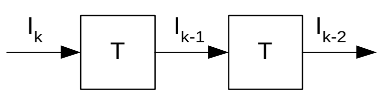
Note: A trajectory consists of a series of 4 or 8 different frequencies equally spaced for each symbol. To achieve a 3 FSK Partial Response, we need a table of 8 trajectories (32 frequencies). The trajectories are pre-calculated to perform the equivalent of DATA filtering.

3. For a binary level "1", the DDS generates frequencies that correspond to trajectories G, C, E and A functions of the two previous bits. Intermediate frequencies are also generated to reach this value at each T/4 (Figure 5).

4. When the data is finished, the DDS generates F0 for a five bit time to perform the RF sine pulse shaping.

Note: The data needs to be precoded NRZI prior to being encoded 3 FSK Partial Response.





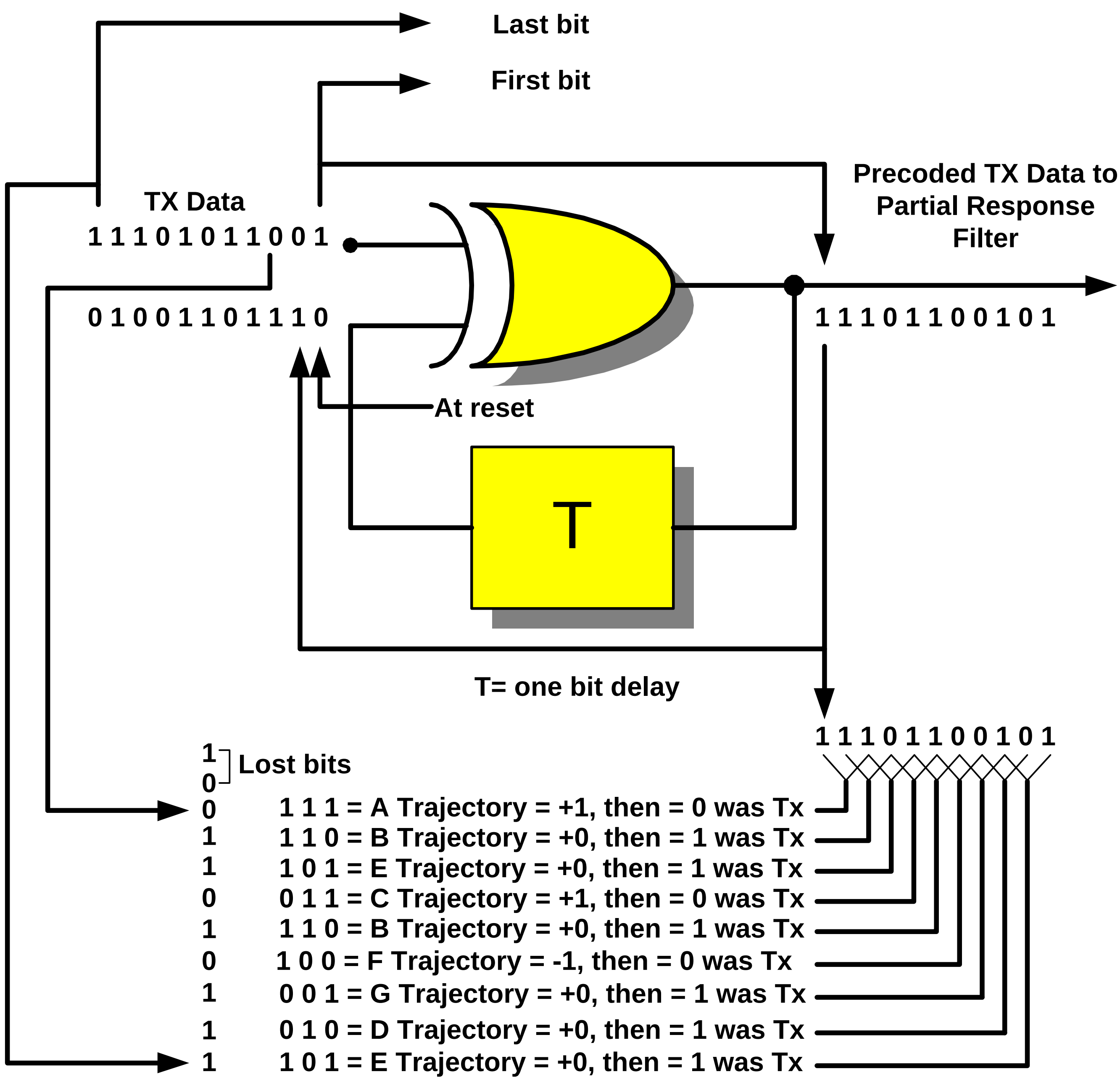
I_k = NRZI precoded data

Two previous bits		New bit	
I_{k-2}	I_{k-1}	I_k	Trajectory for 3FSK, 8 samples per bits
0	0	0	H = (-1.0000 -1.0255,-1.0448, -1.0557,-1.0598, -1.0557,-1.0448, -1.0255)
0	0	1	G = (-1.000,-0.9539, -0.8756, -0.7684,-0.6370,-0.4869, -0.3254,-0.1599)
0	1	0	D = (0.0, +0.0884,+0.1562,+0.1995, +0.2143, +0.1995,+0.1562,+0.0884)
0	1	1	C = (0.0,+0.1599,+0.3254,+0.4869, +0.6370,+0.7684,+0.8756,+0.9539)
1	0	0	F = (0.0,-0.1599,-0.3254,-0.4869,-0.6370,-0.7684,-0.8756,-0.9539)
1	0	1	E = (0.0, -0.0884,-0.1562,-0.1995, -0.2143, -0.1995,-0.1562,-0.0884)
1	1	0	B = (1.000,+0.9539,+0.8756,+0.7684,+0.6370,+0.4869,+0.3254,+0.1599)
1	1	1	A = (1.0000,+1.0255,+1.0448,+1.0557,+1.0598,+1.0557,+1.0448,+1.0255)

Figure 5

Figure 5 shows the deviation index at each T/8 in order to obtain a perfect Partial Response baseband signal with limited RF bandwidth.

Encoding / Decoding Example



Decoding rule: If received +1 or -1 then 0 was transmitted
If received is 0 then 1 was transmitted

Figure 6

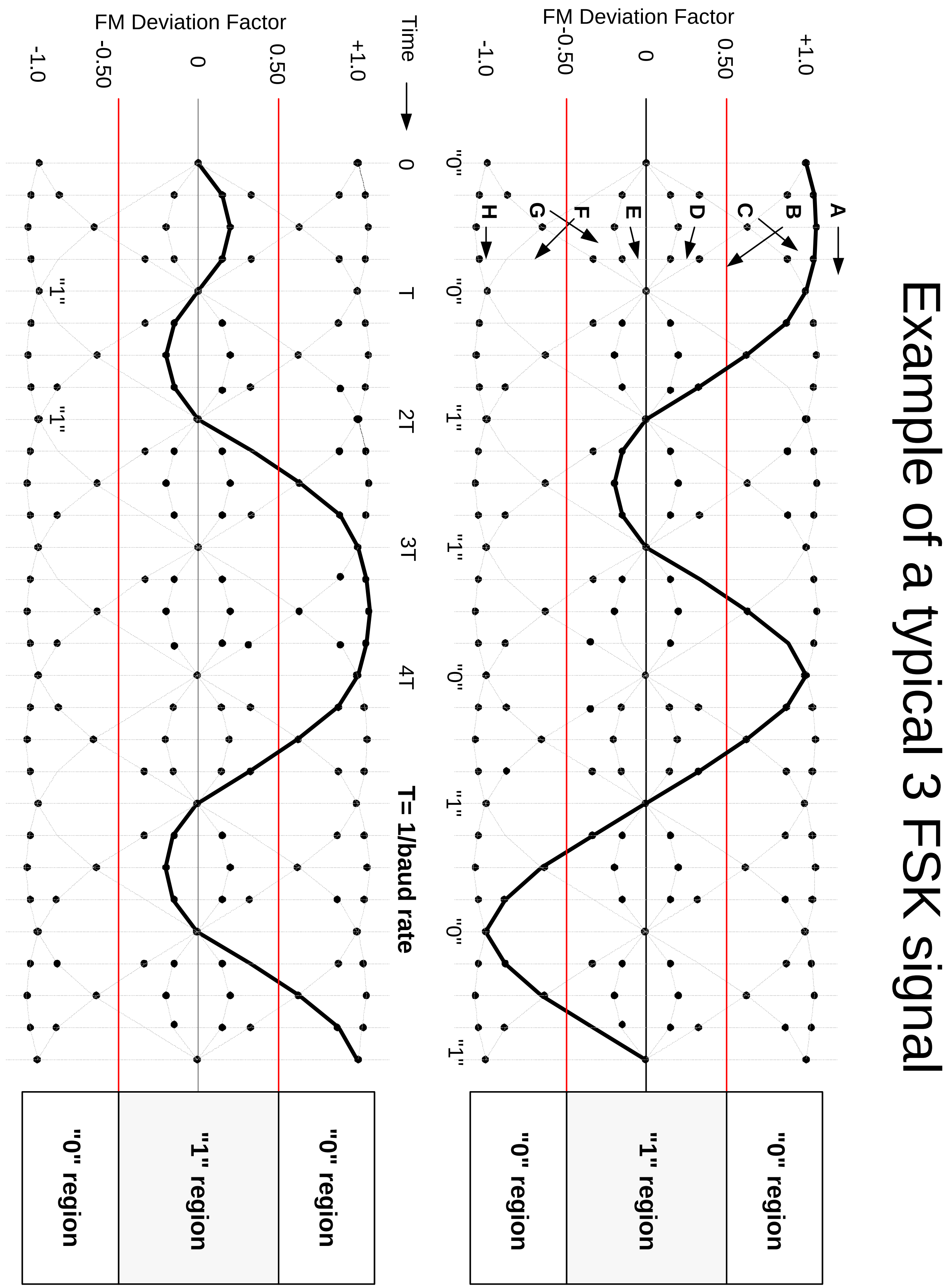

Example of a typical 3 FSK signal
FM Deviation Factor
+1.0
0.50
0
-0.50
-1.0
A
B
C
D
E
F
G
H
"0"
"1"
"0" region
"1" region
"0" region
Time
0
T
2T
3T
4T
T= 1/baud rate

Figure 7

2.2 Up-Converter

The SA900 integrated circuit up-converter was designed by Phillips. In the present application, the SA900 is configured for digital mode (DUAL TX). By using the DUAL path in this IC, the PLL dividers on each side of the phase comparator are equal to one, as opposed to eight when it is selected to AMPS. Only the divider N can be programmed between 6 and 9. In this case, to achieve the optimum choice for the frequency of the VCO tank, the frequency has to be between 80 to 120 MHz. The frequency of 85.6 MHz was chosen because of the factor of 8. Figure 8 represents the relation with all frequencies involved.

The only parameter to select is the divider by N. N was set to 8 as 9600 is easily divided by 8. The bit rate has something to do with this divider because the PLL acts as a multiplier. The index of modulation is also multiplied by 8. To obtain an FSK modulation with an index of 1.0* at 9600 bits/second, the DDS has to generate a delta FM of 600 Hz (4800/8).

*The index of modulation is the ratio of the delta FM over the highest frequency to be modulated. At 9600 baud NRZ, the highest frequency is 4800 Hz.

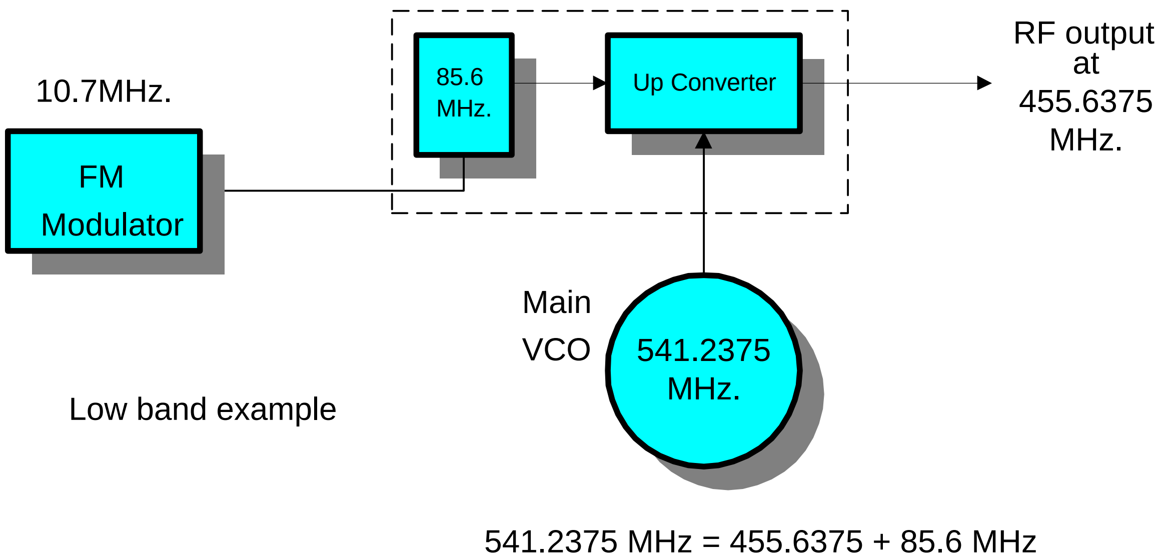


Figure 8

The output signal of the DDS is filtered by one 15 KHz or two 30 KHz (with regard to the channel spacing) ceramic band pass filters to remove two types of anti-aliasing signals. The first anti-aliasing is produced by the DDS, which is the clock frequency minus the actual output signal. The second anti-aliasing is produced by digitally modulating the DDS signal and the discrete signal appears at +/- 4 time the bit rate. The ceramic band pass filter removes all of these anti-aliasing signals and presents a clean reference to the PLL at 85.6 MHz. The DDS signal at 10.7 MHz (sub IF) is applied at the reference input of SA900.

The up-converter in SA900 is designed as an image reject mixer, which helps to reduce up to 40 dBc of all unwanted mixing products. This feature eases the filtering at the output, while choosing a high IF frequency.

Like most ICs in the radio, the SA900 is awoken 2 ms before transmit time of the first bit in order to save DC consumption on the battery.

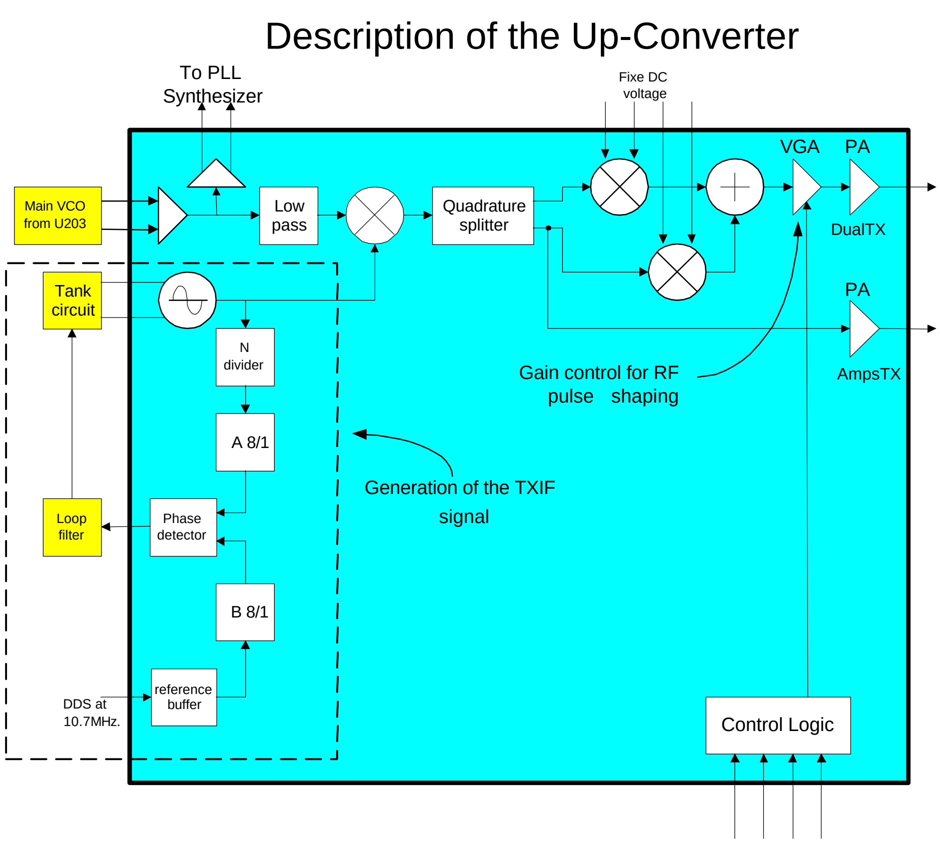


Figure 9

The quadrature modulator is disabled by presenting a fixed DC (differential) voltage at its input. The products of the main VCO and the IF Frequency are multiplied by a fixed voltage to obtain a fixed phase at the output. In doing this, we can have access to the precise gain control amplifier.

A three pole helical (450 MHz) or ceramic (800 MHz) filter removes all the non-desired mixing products at the output of SA900.

2.3 Output Amplifier

The up-converted signal is first filtered and then amplified to 1.5 Watts. This represents about 35 dB of gain from the up-converter. The power amplifier can be matched for 450 MHz applications or 800 MHz with a PCB layout that accepts both configurations. The amplifier is turned on by the TxEn signal at the beginning of the RF pulse shaping sequence (see Chapter 2.4). Two additional power controls are available to produce 3 attenuation steps of 10 dB.

The amplified signal is switched to the antenna with the TX/RX switch. A low pass filter is added after the TX/RX switch to reduce harmonic energy.

3.0 Transmitter Control Software Description

3.1- Advanced test jig:

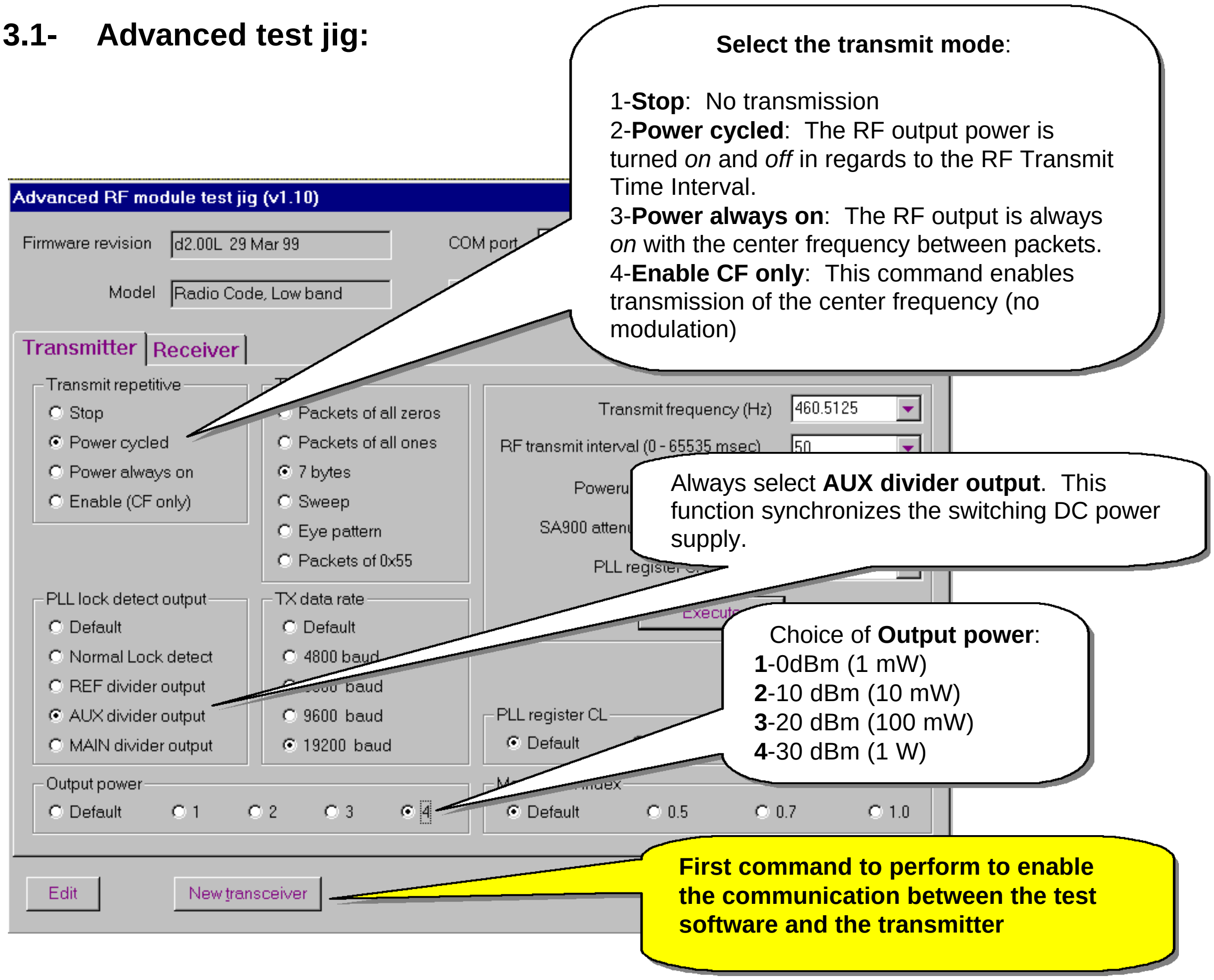


Figure 1

The Advanced RF module test jig allows the engineer or technician to have access and control of most of the parameters of the transmitter and receiver. The first step is to initiate the **New transceiver** command; the Firmware revision and the Model should appear at the top.

The second step is to select the output frequency in the format 465.5125; the dot is important and the frequency can be entered in directly.

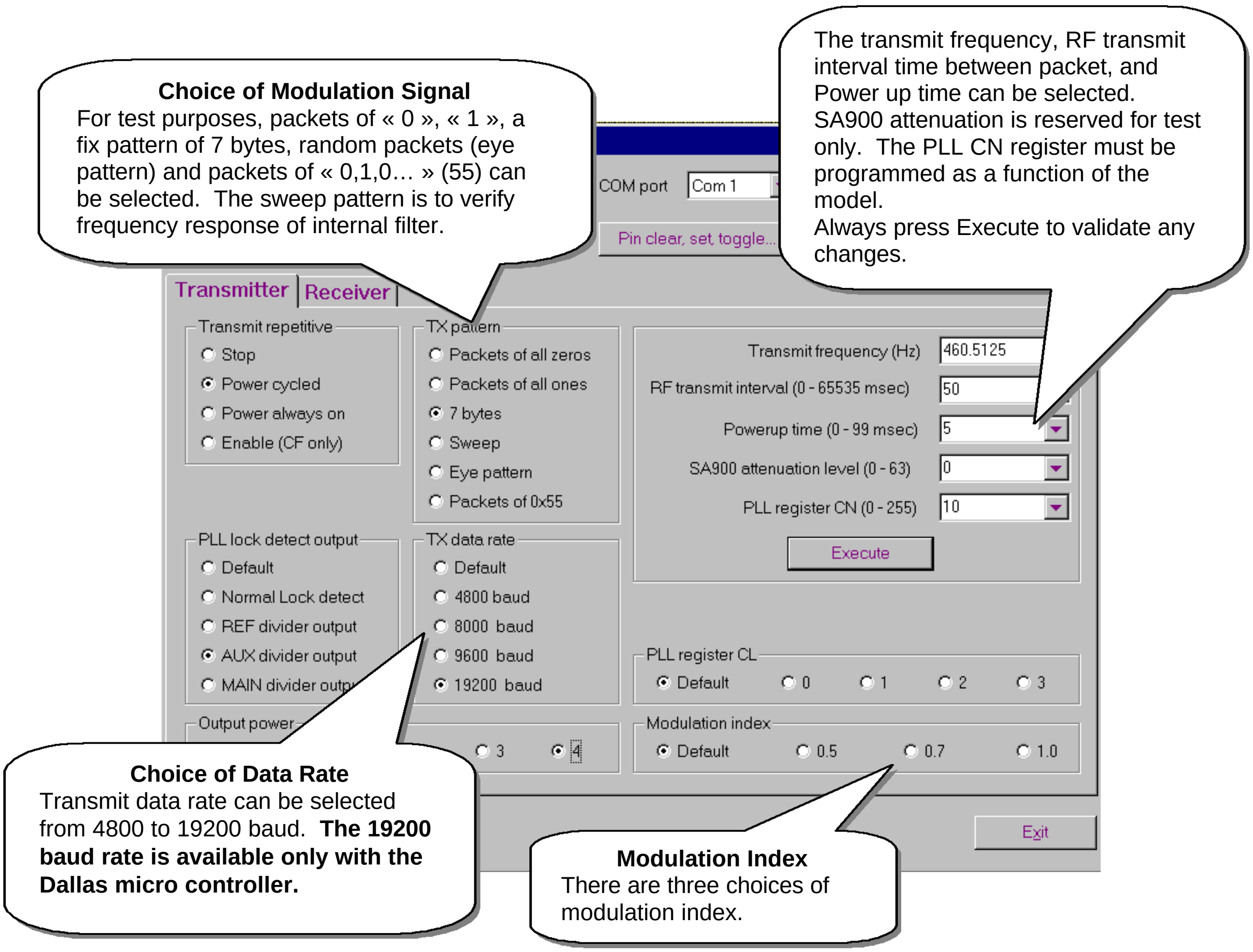

Choice of Modulation Signal
For test purposes, packets of « 0 », « 1 », a fix pattern of 7 bytes, random packets (eye pattern) and packets of « 0,1,0… » (55) can be selected. The sweep pattern is to verify frequency response of internal filter.
The transmit frequency, RF transmit interval time between packet, and Power up time can be selected. SA900 attenuation is reserved for test only. The PLL CN register must be programmed as a function of the model.
Always press Execute to validate any changes.
COM port
Com 1
Pin clear, set, toggle...
Transmitter
Receiver
Transmit repetitive
Stop
Power cycled
Power always on
Enable (CF only)
TX pattern
Packets of all zeros
Packets of all ones
7 bytes
Sweep
Eye pattern
Packets of 0x55
Transmit frequency (Hz)
460.5125
RF transmit interval (0 - 65535 msec)
50
Powerup time (0 - 99 msec)
5
SA900 attenuation level (0 - 63)
0
PLL register CN (0 - 255)
10
Execute
PLL lock detect output
Default
Normal Lock detect
REF divider output
AUX divider output
MAIN divider outp
TX data rate
Default
4800 baud
8000 baud
9600 baud
19200 baud
PLL register CL
Default
0
1
2
3
Output power
3
4
Modulation index
Default
0.5
0.7
1.0
Exit
Choice of Data Rate
Transmit data rate can be selected from 4800 to 19200 baud. **The 19200 baud rate is available only with the Dallas micro controller.**
Modulation Index
There are three choices of modulation index.

Figure 2

Test Procedure RF Board

The test procedure consists of adjusting the TCXO frequency and verifying all of the parameters required for normal operation.

Temperature testing will be carried out on 10% of the production and a burn-in of 12 hours at $60^{o}C$ will be done on all of the radios before the testing. All measurements will be noted on a spread sheet for each radio.

Test 1 - Programming and TCXO Adjustment

Set-up

Test # 1 consists of programming the radio with test firmware Tx_ocu.bin and adjusting the TCXO. The following set-up is required:

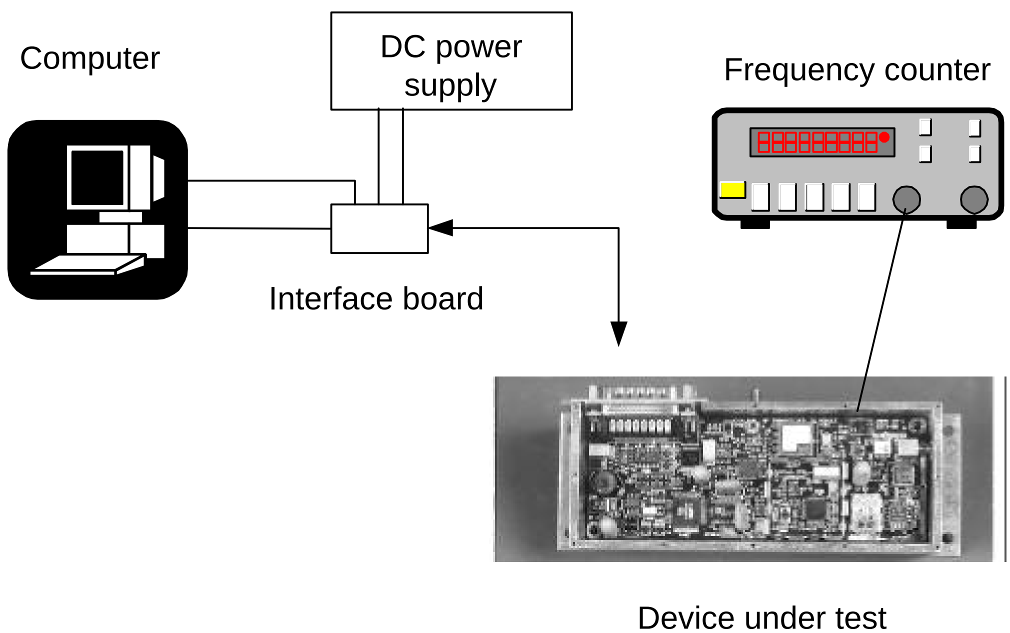


Figure 1

Description of the test jig for adjusting the TCXO

The computer needs the following programs:

- TestComJig.exe Window software for testing
- Software for the ATMEL 8953 and adapter
- Spread sheet software, ex. Excel
- CANAC test firmware Tx_ocu.bin , BURN.

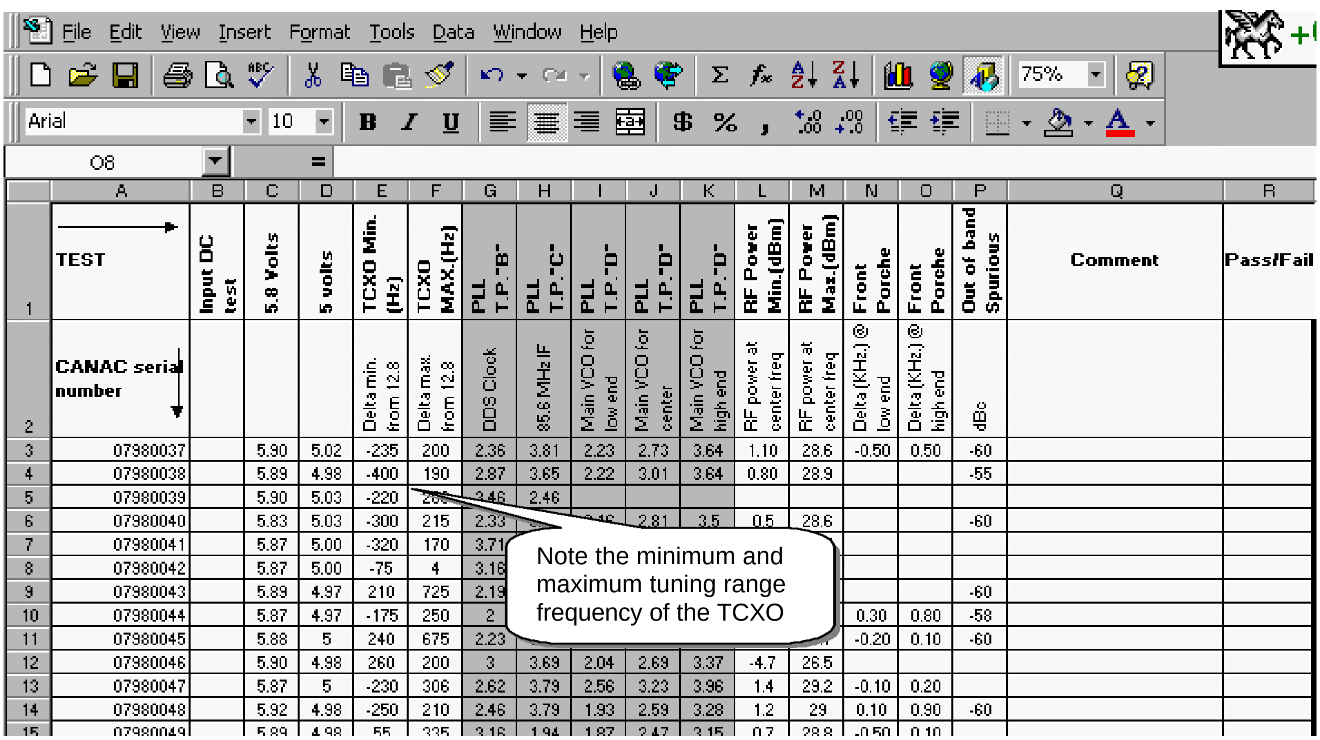
The DC power supply must provide at least 15 volts @ 1 amp. well regulated. The interface board is supplied by CANAC.

Procedure

1- Connect the device under test (D.U.T.) as shown in figure 1 and turn on the power supply. With a voltmeter, measure 5.8 volts +/- 5 % at the junction of L701 and C704. Next, measure 5 volts +/- 5 % at pin 1 of U702.

2- Download the CANAC test firmware to the radio, Tx_ocu.bin.

3- Connect a scope probe on pin 6 of P501 to a frequency counter and note the minimum and maximum frequency of the TCXO (Figure 2). Check and note the minimum and maximum tuning range of the TXCO , then adjust the frequency to 12.8 MHz better than +/- 4 Hz.



	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R
1	TEST	Input DC test	5.8 Volts	5 volts	TCXO Min. (Hz)	TCXO MAX.(Hz)	PLL T.P."B"	PLL T.P."C"	PLL T.P."D"	PLL T.P."D"	PLL T.P."D"	RF Power Min.(dBm)	RF Power Max.(dBm)	Front Porche	Front Porche	Out of band Spurious	Comment	Pass/Fail
2	CANAC serial number				Delta min. from 12.8	Delta max. from 12.8	DDS Clock	85.6 MHz IF	Main VCO for low end	Main VCO for center	Main VCO for high end	RF power at center freq	RF power at center freq	Delta (KHz.) @ low end	Delta (KHz.) @ high end	dBc		
3	07980037		5.90	5.02	-235	200	2.36	3.81	2.23	2.73	3.64	1.10	28.6	-0.50	0.50	-60		
4	07980038		5.89	4.98	-400	190	2.87	3.65	2.22	3.01	3.64	0.80	28.9			-55		
5	07980039		5.90	5.03	-220	[illegible]	3.46	2.46										
6	07980040		5.83	5.03	-300	215	2.33	[illegible]	[illegible]	2.81	3.5	0.5	28.6			-60		
7	07980041		5.87	5.00	-320	170	3.71	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]					
8	07980042		5.87	5.00	-75	4	3.16	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]					
9	07980043		5.89	4.97	210	725	2.19	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]			-60		
10	07980044		5.87	4.97	-175	250	2	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.30	0.80	-58		
11	07980045		5.88	5	240	675	2.23	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-0.20	0.10	-60		
12	07980046		5.90	4.98	260	200	3	3.69	2.04	2.69	3.37	-4.7	26.5					
13	07980047		5.87	5	-230	306	2.62	3.79	2.56	3.23	3.96	1.4	29.2	-0.10	0.20			
14	07980048		5.92	4.98	-250	210	2.46	3.79	1.93	2.59	3.28	1.2	29	0.10	0.90	-60		
15	07980049		5.89	4.98	55	335	3.16	1.94	1.87	2.47	3.15	0.7	28.8	-0.50	0.10			

Figure 2

This figure is an example of the information accumulated on each transmitter.

Test 2 - Synthesizer Verification

This verification is to confirm the proper operation of the radio by verifying the range of operation of each PLL.

Set-up

Test # 2 consists of measuring and noting on the spread sheet all three PLL control voltages when locked (Figure 5). The RF test frequency is a function of the model number; for a 450 to 460 MHz radio, tests will be carried out at 450.5125, 455.5125 and 460.5125 MHz. Always choose the minimum, middle and maximum operating frequency for a given model number.

Set the transmitter in continuous mode with no modulation by enabling CF (center frequency) only. The next figure shows the command to select and the result on the spectrum analyzer for this test

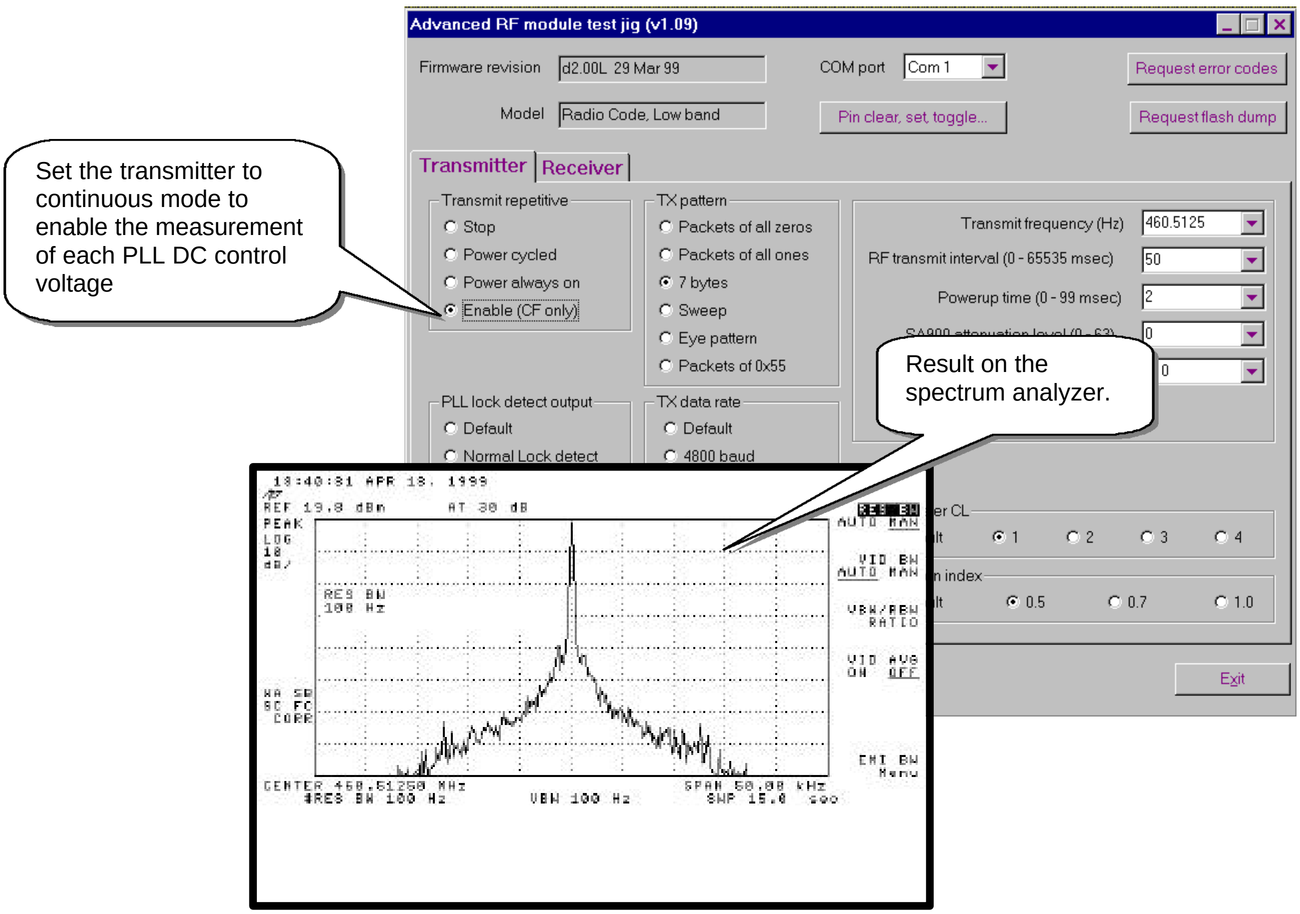


Figure 3

Procedure

1- The first PLL control voltage: This is the 25.6 MHz PLL and the measurement is at the junction of **R109 and C116** (T.P. B).

2- The second PLL control voltage: This the 85.6 MHz PLL and the measurement is at the junction of **C502 and D501** (T.P. C).

3- The third PLL control voltage: This is the main VCO (IF + RF output frequency) and the measurement is at the junction of **R108 and C108** (T.P. D). Note the control voltage for the minimum, middle and maximum frequency.

These measurements are sensitive to parasitic capacitance and a voltmeter must be used.

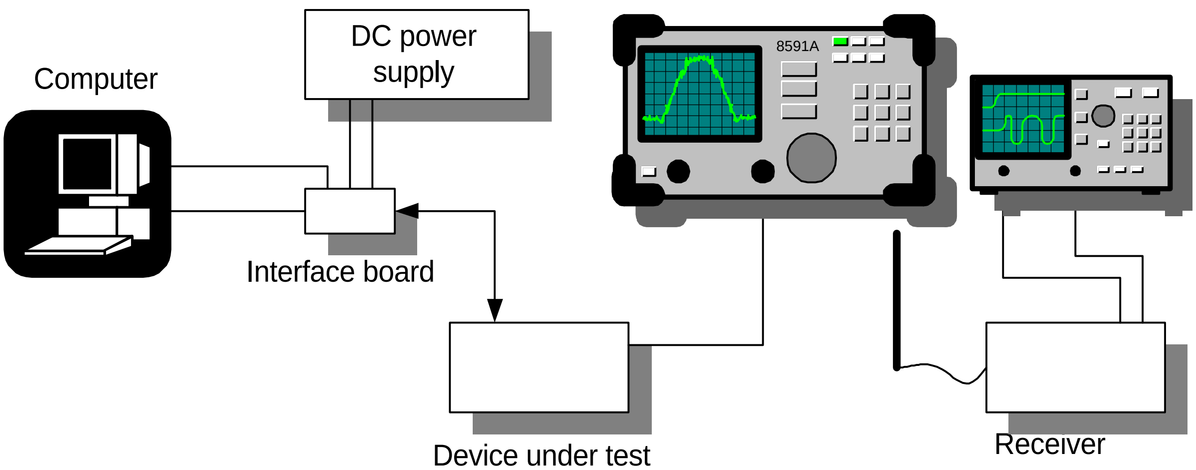
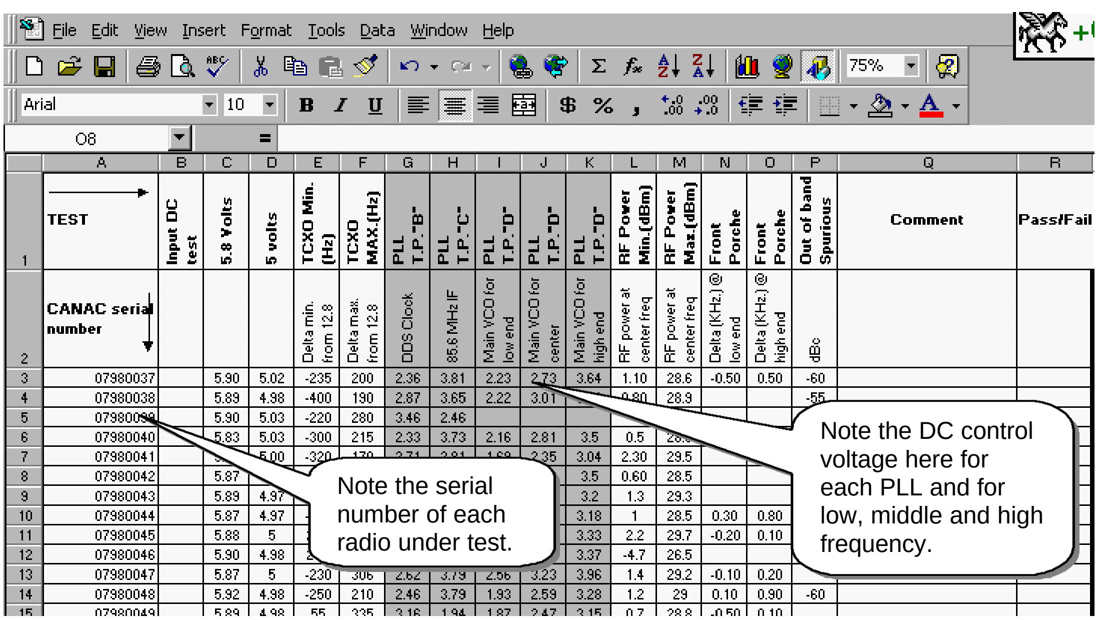


Figure 4

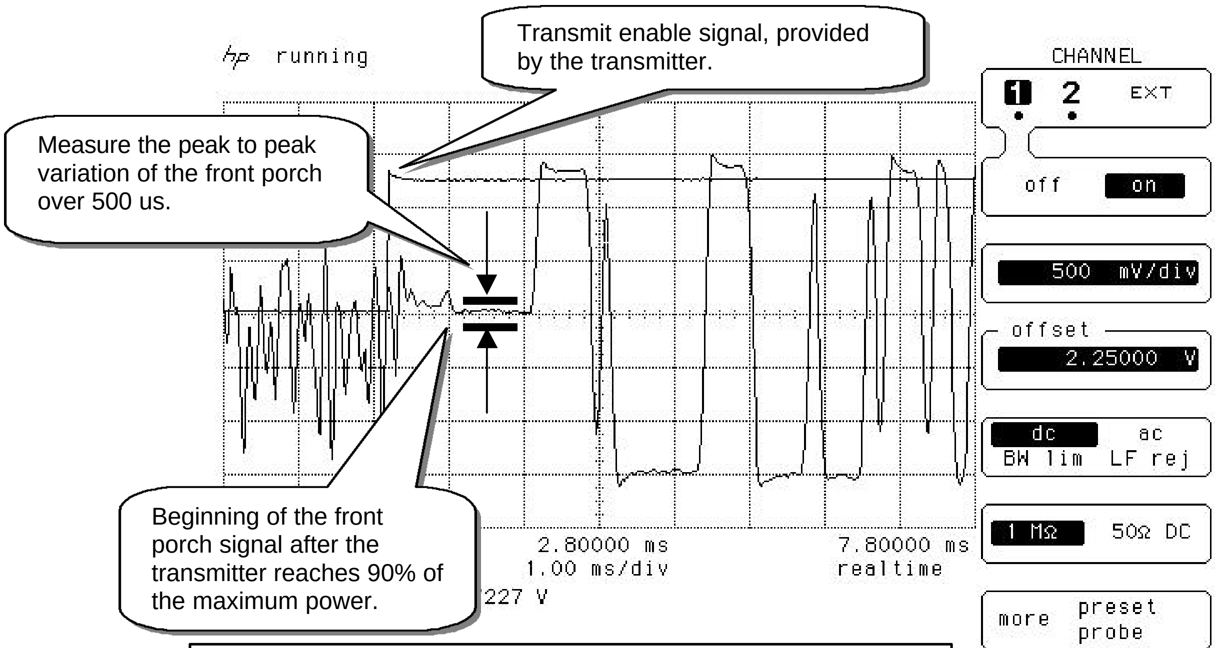


	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R
1	TEST	Input DC test	5.8 Volts	5 volts	TCXO Min. (Hz)	TCXO MAX.(Hz)	PLL T.P."B"	PLL T.P."C"	PLL T.P."D"	PLL T.P."D"	PLL T.P."D"	RF Power Min.(dBm)	RF Power Max.(dBm)	Front Porche	Front Porche	Out of band Spurious	Comment	Pass/Fail
2	CANAC serial number				Delta min. from 12.8	Delta max. from 12.8	DDS Clock	85.6 MHz IF	Main VCO for low end	Main VCO for center	Main VCO for high end	RF power at center freq	RF power at center freq	Delta (KHz.) @ low end	Delta (KHz.) @ high end	dBc		
3	07980037		5.90	5.02	-235	200	2.36	3.81	2.23	2.73	3.64	1.10	28.6	-0.50	0.50	-60		
4	07980038		5.89	4.98	-400	190	2.87	3.65	2.22	3.01	[illegible]	0.80	28.9			-55		
5	[illegible]		5.90	5.03	-220	280	3.46	2.46				[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
6	07980040		5.83	5.03	-300	215	2.33	3.73	2.16	2.81	3.5	0.5	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
7	07980041		[illegible]	5.00	-320	[illegible]	[illegible]	[illegible]	[illegible]	2.35	3.04	2.30	29.5	[illegible]	[illegible]	[illegible]	[illegible]	
8	07980042		5.87	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	3.5	0.60	28.5		[illegible]	[illegible]	[illegible]	
9	07980043		5.89	4.97	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	3.2	1.3	29.3		[illegible]	[illegible]	[illegible]	
10	07980044		5.87	4.97	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	3.18	1	28.5	0.30	0.80	[illegible]	[illegible]	
11	07980045		5.88	5	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	3.33	2.2	29.7	-0.20	0.10	[illegible]	[illegible]	
12	07980046		5.90	4.98	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	3.37	-4.7	26.5			[illegible]	[illegible]	
13	07980047		5.87	5	-230	306	2.62	3.79	2.56	3.23	3.96	1.4	29.2	-0.10	0.20	[illegible]	[illegible]	
14	07980048		5.92	4.98	-250	210	2.46	3.79	1.93	2.59	3.28	1.2	29	0.10	0.90	-60		
15	07980049		5.89	4.98	55	335	3.16	1.94	1.87	2.47	3.15	0.7	28.8	-0.50	0.10			

Figure 5

Test 3 - Frequency Pulling Verification.

Test # 3 consists of measuring and noting on the spread sheet the peak-to-peak voltage or the equivalent frequency variation of the front porch signal of the demodulated signal. This will help to characterise the pulling effect at the beginning of a transmission. The limit for Canac systems is +/- 400 Hz.



$$\frac{\text{(Peak to peak variation of the front porch)}}{\text{(Peak to peak DATA voltage)}} \times \frac{\text{Baud rate}}{2}$$

Figure 6

This figure shows how to measure the front porch variation.

Test 4 - Temperature Testing.

Test # 4 consists of measuring and noting the variation of the output frequency versus temperature. Load the burn-in software for this test.

Set up

Refer to the set up in figure 7 and install the DUT inside the temperature chamber.

Procedure

Bring the temperature to –40°C. Allow 5 minutes for stabilisation. Turn on the power supply. After 5 minutes, measure the output frequency with a 1 GHz frequency counter (in continuous mode low power).

Tests can be carried out in groups of ten radios. Prepare ten radios with the burn-in software and connect each radio to the DC power supply at the same time. Install all the powered radios inside the temperature chamber and perform frequency measurements as follows on each radio.

Stop the cooling system, and note the RF frequency at each 10 ° up to + 60 °C by connecting the RF output to a frequency counter. Fill the temperature test spread sheet (TT1-2MOD-6413) prepared for this purpose.

Test 5 - Out of band spurious emission

1- Set the radio for normal operation. Set the SPAN of the spectrum analyzer to **500 MHz** with a resolution bandwidth of 30 KHz at a CENTER FREQ of the test frequency and note the maximum peak energy of any spurious with the MAX HOLD function after 30 seconds.

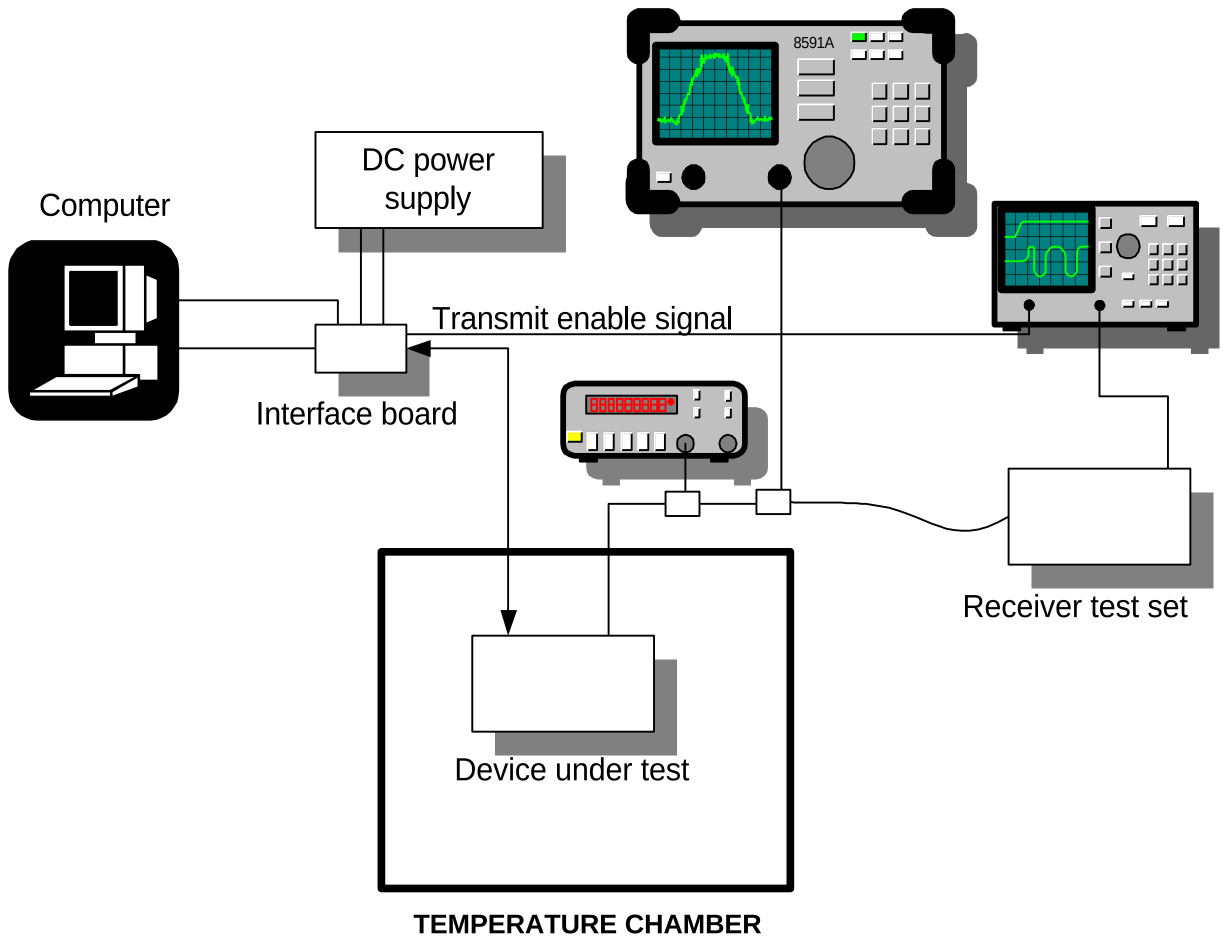

Computer
DC power supply
8591A
Transmit enable signal
Interface board
Receiver test set
Device under test
TEMPERATURE CHAMBER

Figure 7

FCC Compliance

The RF Transmitter 450MHz Module has been tested to meet the FCC part15 and part 90.

This device complies with Part 15 of the FCC Rules. Operation of this device is subject to the following two conditions: (1) This device may not cause harmful interference, and (2) this device must accept any interference received, including interference that may cause undesired operation.

NOTE: This equipment has been tested and found to comply with the limits for a Class B digital device, pursuant to Part 15 of the FCC Rules. These limits are designed to provide reasonable protection against harmful interference in a residential installation. This equipment generates, uses, and can radiate radio frequency energy and, if not installed and used in accordance with the instructions, may cause harmful interference to radio communications. However, there is no guarantee that interference will not occur in a particular installation. If this equipment does cause harmful interference to radio or television reception, which can be determined by turning the equipment off an on, the user is encouraged to try to correct the interference by one or more of the following measures:

- Reorient or relocate the receiving antenna.
- Increase the separation between the equipment and receiver.
- Connect the equipment into an outlet on a circuit different from that to which the receiver is connected.
- Consult the dealer or an experienced radio/TV technician for help.

Any changes made by the user not approved by Canac Inc. can void the user's authority to operate the equipment.