

1 Introduction

This document contains details of a number of improvements and enhancements that may be made to the circuit of the DE70321 / DE70321T AIS Demonstration Kits. Information is included for both transponder (DE70321T) and receive only (DE70321) applications. This consolidates the information from previous application notes together with some further suggestions.

To meet the demanding adjacent channel rejection standard for Class B transceiver operation, the 1st local oscillators require excellent phase noise performance. It is suggested that the receivers are operated using an external, dual PLL IC and one of the CMX7032 ones is used for transmit.

It should be noted that some of these enhancements and will require modifications to the component layout. Any component values provided are given as a guide only and are subject to changes due to layout parasitics and tolerances within a given design.

The information supplied is provided for the benefit of those wishing to incorporate the CMX7032/CMX7042 and elements of the DE70321 / DE70321T into their own AIS transponder or receiver design.

In addition to the data in this document further test results can be found in reference [3].

2 History

Version	Changes	Date
2.0	Replacement of obsolete LMX2332 PLL. Enhancement to co-channel performance (CD3 and CD4). Further enhancement to VCO for increased tx isolation.	16-09-10
1.0	First release Consolidates Application Notes, 'DE70321T Tx Transient Response' and 'DE70321 VCO and Sensitivity Enhancement' with Information Note, 'Enhancement Information and Errata' and Erratum, 'Erratum to DE70321 Schematic HiRes Drawings'. Adds more enhancements to further improve performance.	14-5-10

3 Contents

1	Introduction	1
2	History	1
3	Contents	2
4	VCO Production Tolerances	3
4.1	Analysis	3
4.2	Recommendations	4
4.2.1	Receiver VCOs	4
4.2.2	Transmitter VCO	5
5	Receiver recommendations	6
5.1	Receiver A VCO changes	6
5.1.1	RxA VCO trimming	6
5.1.2	RxA LO Phase Noise improvements	6
5.1.3	RxA VCO tuning characteristics – parallel resonator	6
5.2	Receiver B VCO changes	10
5.2.1	RxB VCO trimming	10
5.2.2	RxB Phase Noise improvements	10
5.2.3	RxB VCO tuning characteristics – parallel resonator.	10
5.3	Rx PLL synthesiser replacement	12
5.4	Other receiver issues	13
5.4.1	Receive mixer diodes	13
5.4.2	Receiver DC level adjustment	13
5.5	Receive only sensitivity enhancements	14
6	Transmitter recommendations	16
6.1	Tx modifications	16
6.1.1	Tx VCO trimming	16
6.1.2	Tx VCO buffer output/divider input	16
6.1.3	Power amplifier	18
6.1.4	RAMDAC table	18
7	Transmitter system performance	19
7.1	Continuous output	19
7.2	Packet 'slotted' transmission	20
7.3	References	21
8	Annexe B – Earlier Enhancements to DE70321/DE70321T	23
8.1	B.1 Mod state 4 or below:	23
8.1.1	B.1.1 Receiver DC Coupling	23
8.1.2	B.1.2 VCTCXO Tuning Improvement	24
8.2	B.2 Mod State 3 and Below	25
8.3		25
8.4	B.3 Errata	25
8.5		25
9	Annexe C Glossary of terms	26

4 VCO Production Tolerances

4.1 Analysis

Since release, the DE70321's tuning voltages for the RxA, RxB and Tx PLL's have been recorded for the transceiver configuration. When grouped together, statistical analysis can be performed to deduce the potential production spreads resulting from component tolerances, placement skew of inductors and other automated procedures that influence final test performance. The results follow:

Oscillator	RxA	RxA	RxB	RxB	Tx	Tx
FMHz	117.170	123.170	126.77	132.77	312.050	324.050
Avg. Tuning V	1.694	3.883	1.292	4.156	0.536	2.278
Min. Tuning V	1.380	3.060	1.030	3.040	0.110	1.910
Min % below Avg	18.525	21.186	20.274	26.849	79.481	16.160
Max. Tuning V	1.950	4.700	1.570	4.930	1.060	2.800
Max % above Avg	15.128	21.055	21.524	18.630	97.733	22.907
Standard Deviation (σ)	0.12	0.39	0.08	0.39	0.20	0.19

Table 1 - Average, min/max and standard deviation over 5 batches of DE70321's

From this analysis, and assuming that a larger population continues to follow a normal distribution, the following assumptions can be made.

For the receivers, less than 5% would hit the upper limit of tuning voltage due to VCO tolerances (95% within $\pm 2\sigma$). This is based on calculation of the standard deviation and comparing this to the minimum and maximum values observed. At $>4.95V$ the PLL would be at the maximum tuning voltage for the LMX2332 / ADF4216 and on the edge of being out of lock. At least $\pm 0.4V$ should also be allowed for temperature variation with the varactor diodes.

	-2σ on lowest frequency	Minimum measured	$+2\sigma$ on highest frequency	Maximum measured
RxA	1.46	1.38	4.65	4.70
RxB	1.13	1.03	4.95	4.93

Table 2 – Two-sigma (95%) tuning values for the receiver VCO's

For the transmitter, less than 0.25% would hit the upper tuning due to VCO tolerances (99.75% within $\pm 3\sigma$). The tuning voltage at minimum frequency is of little concern, because in reality the transmitter has to cover only the top 525kHz of the band (1050kHz at the VCO frequency). At $>3V$ the PLL would be at the maximum of the available range for the CMX7032 and on the edge of being out of lock. Again at least $\pm 0.3V$ headroom should be allowed for temperature variation.

	-3σ on lowest frequency	Minimum measured	$+3\sigma$ on highest frequency	Maximum measured
Tx	0.06	0.11	2.86	2.80

Table 3 – Three-sigma (99.75%) tuning values for the transmitter VCO

Typical variation of the VCO control voltages with temperature on DE70321 / DE70321T are shown in Table 4.

Temperature / Degrees C							
	-25	-15	0	20	40	55	70
Tx 156 MHz	0.36	0.4	0.48	0.6	0.73	0.81	0.89
Tx 162 MHz	2.05	2.1	2.17	2.29	2.4	2.47	2.57
RxB	3.55	3.59	3.66	3.8	3.91	4.02	4.12
RxA	3.61	3.67	3.77	3.95	4.1	4.23	4.36

Table 4 – Typical variation in VCO control voltage with temperature

4.2 Recommendations

4.2.1 Receiver VCOs

The largest source of receiver error is in the placement and soldering of the tuning inductors, now specified as 2% tolerance. The inductors could be skewed on their pads in placement / reflow and a variable amount of solder flows along the leads, resulting in small changes in value. Normally a re-seating of the component or slight twist of the component body is sufficient to bring the tuning voltage to an acceptable level.

This degree of rework may be acceptable for very low volume production but a different approach is required for larger scale production as the standard deviation is high. Whilst the capacitors could be more closely specified, this can become prohibitively expensive so some means of adjustment is preferred.

For the RxA VCO, details of a trimmer circuit can be found in 5.1.1 and a similar arrangement for the RxB VCO can be found in 5.2.1. The results of these alterations are given in Table 5.

F / MHz	RxA			RxB		
	117.170	120.170	123.170	126.770	129.770	132.770
Vtune with original fixed values	1.74	-	4.04	1.28	-	4.04
After Modification						
Vtune Cmin	0.95	1.44	1.95	0.72	1.29	2.08
Vtune Cmid	1.6	2.34	3.5	1.34	2.36	4.55
Vtune Cmax	1.92	2.94	4.93	1.65	2.98	4.93
Vtune (adjusted)	1.78	-	4.19	1.33	-	4.20
Phase noise dBc/Hz @ 25kHz	-	-	-125	-	-	-128.3
Tuning sensitivity MHz/V	-	2.49	-	-	2.09	-

Table 5 – Rx VCO test results for DE70321 s/n 198389

The phase noise is measured as this is a critical parameter in determining the adjacent channel rejection performance of the receiver. RxA is slightly better due to the lower tuning sensitivity, but both have adequate margin.

In practice, when implemented onto a PCB design, the required circuit values are likely to change slightly due to layout parasitics. It would be best if the trimmer capacitors were placed on the top side of the PCB for ease of adjustment. It is possible that these could fit inside the IF circuit areas with a via to the VCO circuits underneath. The cost benefit of the additional trimmer components and adjustment need to be weighed against the cost of rework and re-test.

It is recommended that the footprints for the trimmer solution be added to the PCB but the standard circuit values be used initially and production yield monitored. The trimmers can then be added at a later date if necessary.

4.2.2 Transmitter VCO

Variation in the transmitter tuning voltage comes from all the components in the resonator. While the inductor is already specified as 2%, the capacitors C218, C222, C217 and C208 could be specified with tighter tolerance than the standard $\pm 0.25\text{pF}$.

To avoid the use of different components to the receiver, it is suggested that the same 6-30pF trimmer capacitor could be used. In practice this component should be placed on the top side of the PCB with a via to the Tx VCO section underneath.

The VCO operates over 312-324 MHz and so a different approach is taken with the transmitter so that changes to the resonator section can be avoided. C206 (collector to emitter feedback on the oscillator transistor TR12) is reduced from 15pF to 10pF. An additional series combination of 22pF with a 6-30pF trimmer to ground is added at the transistor emitter. Effectively C206 and the new trimmer arrangement are in parallel, allowing the capacitance to be varied between approximately 14pF and 22pF. (Details in section 6.1.1). As the variable is reasonably isolated from the resonator and varactor, the tuning sensitivity remained unchanged at approximately 6.9MHz/V. The phase noise performance, whilst not as critical for the transmitter, should remain relatively unchanged. If this approach were implemented, it is recommended that the capacitor be adjusted to give a tuning voltage of 2.1-2.3V at 324.050MHz.

	Tx		
FMHz	312.050	318.050	324.050
Vtune with original fixed values	0.24	-	1.98
After Modification			
Vtune Cmin	0.15	1.05	1.89
Vtune Cmid	0.63	1.52	2.35
Vtune Cmax	0.83	1.72	2.56
+/-V from mid adjust range	0.34	0.335	0.335

Table 6 – Tx VCO test results for DE70321 s/n 198389

Whilst the tolerances for the transmitter appear to be less critical, again it is recommended that the existing circuit values be used initially, possibly with improved tolerance capacitors, and the yield monitored. However the layout should incorporate footprints for the trimmer solution so that this can be implemented if required.

5 Receiver recommendations

5.1 Receiver A VCO changes

5.1.1 RxA VCO trimming

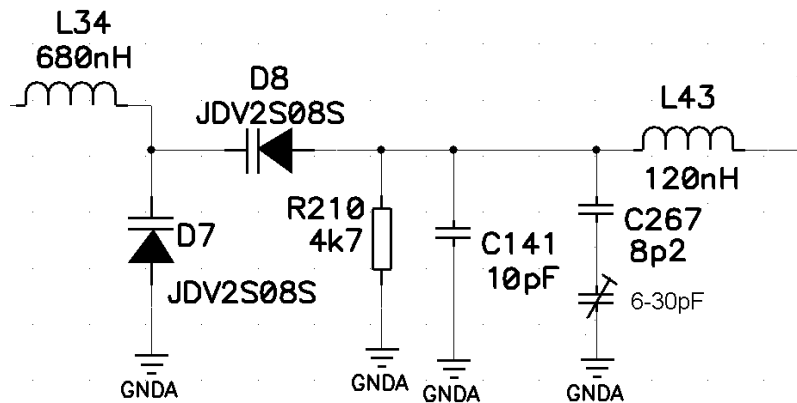


Figure 1 - Addition of a trimmer capacitor in RxA VCO

The following modifications detail how a trimmer capacitor may be added to a user's implementation to allow adjustment of the VCO tuning voltages in production. With reference to the DE70321 schematic:

- C141 changes from 12pF to 10pF.
- C267 changes from 3.9pF connected to ground, to a 8.2pF capacitor in series with at Murata TZC3P300A110B00 6.5pF to 30pF trimmer capacitor.

5.1.2 RxA LO Phase Noise improvements

The following modifications have also been shown to improve phase noise at 25kHz by approximately 2dB. These changes use values already on the bill of materials. This increases the current drawn by the stage by approximately 2mA.

- R135, change from 4k7 to 1k8.
- R109, change from 4k7 to 1k8.
- R114, change from 100R to 68R.
- C248, change from NF to 100nF.

5.1.3 RxA VCO tuning characteristics – parallel resonator

These changes would improve the adjacent channel rejection, limited by phase noise. This may be required for AIS class A applications where performance must be maintained across the whole marine band. The existing design is sufficient for Class B or Rx Only applications.

Note that this shows the original circuit and does not incorporate the modifications of earlier sections. Incorporating both these and earlier LO enhancements would results in exceptional phase noise performance across the whole marine band. Including trimming components into the parallel resonator circuit would require changes in values.

The RxA VCO is designed to cover 117.170 to 123.170 MHz within a tuning voltage range of roughly 1V to 4V (i.e. 156.025-162.025 MHz less the 38.855MHz IF). An extract from the schematics [2], giving the circuit of the VCO, is shown in Figure 2.

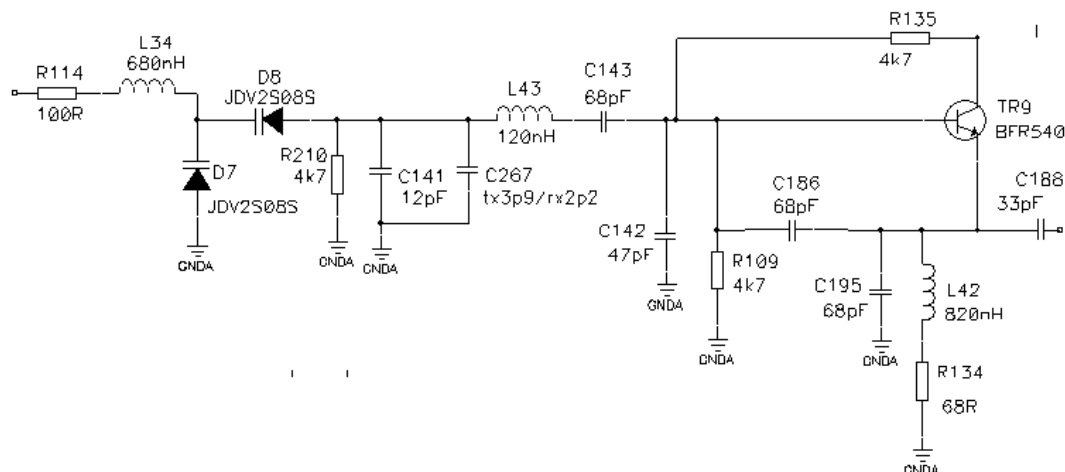


Figure 2 - The original RXA VCO circuit

Effectively the above circuit tunes a series LC reactance, where the capacitance is a combination of D7, D8, C141 and C267. Both L43 and D8 are ungrounded. For measurements, the output is taken from the TR10 amplifier output (see [2]) that would normally drive the diode ring mixer.

The phase noise is measured at four points across the band, as shown in Table 7.

Frequency (MHz)	V tune (V)	Output Power via buffer amp (dBm)	Phase Noise at 25kHz offset
114	1.01	11.5	-118.7 dBc/Hz
117	1.59	11.35	-120.9 dBc/Hz
120	2.36	11.15	-122.8 dBc/Hz
123	3.57	10.9	-125.6 dBc/Hz

Table 7- Initial RXA VCO performance

The VCO gain (K_v) varies considerably from around 2MHz/V at the top of the band to 4.5MHz/V at the bottom, as both series and shunt elements of the resonator are tuned. The increased K_v results in degraded phase noise performance at the bottom of the band. Approximately 7dB variation in phase noise performance across the band has been measured.

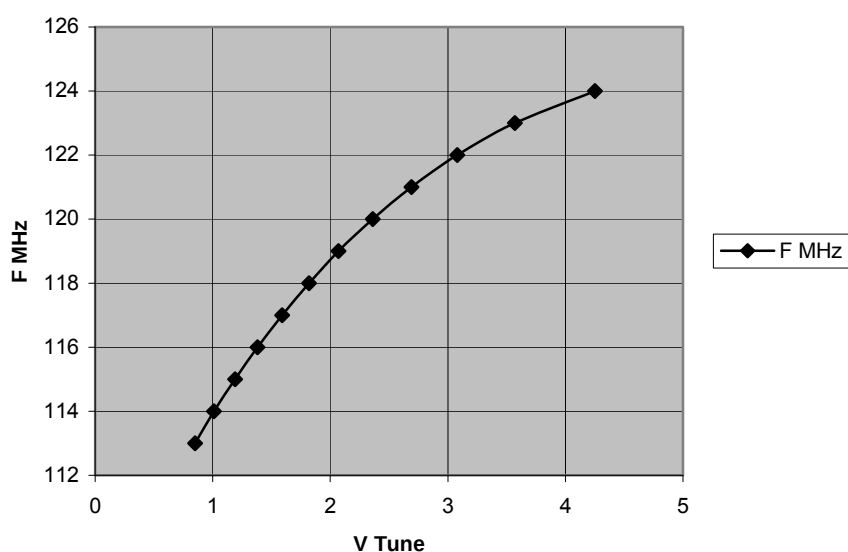


Figure 3 – Original RXA VCO frequency against tuning voltage

The VCO was changed as follows:

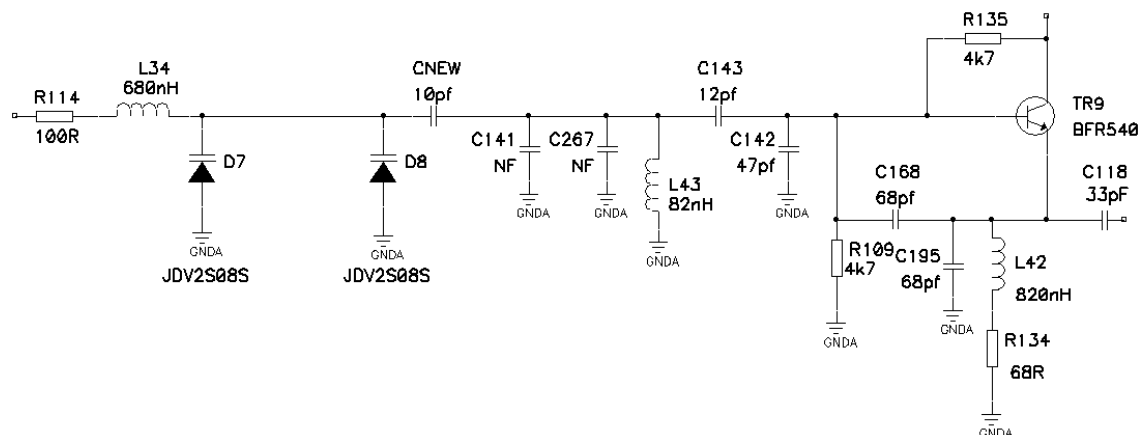


Figure 4 – RXA ‘parallel’ resonator circuit

The resonator is converted to use the tuning diodes and inductor in parallel. The diodes are paralleled (to reduce the overall ESR) and coupled to the tank circuit via a fixed coupling capacitor. The inductor is lower in value and has one end grounded. The negative impedance generator and output coupling remained unchanged.

Frequency (MHz)	V tune	Output Power via buffer amp (dBm)	Phase Noise at 25kHz offset
114.5	0.24	9.80	-127.9 dBc/Hz
115	0.48	9.75	-127.8 dBc/Hz
117	1.40	9.65	-127.2 dBc/Hz
120	2.61	9.40	-125.7 dBc/Hz
123	3.94	9.15	-124.6 dBc/Hz

Table 8 - Modified RXA VCO performance

Although about 2dB lower in absolute terms, the variation in output power was still around 0.5dB across the band. From the graph below, it can be seen that the tuning is much more linear. The VCO gain K_v only varies from around 2.1MHz/V at the top of the band to around 2.2MHz/V at the bottom.

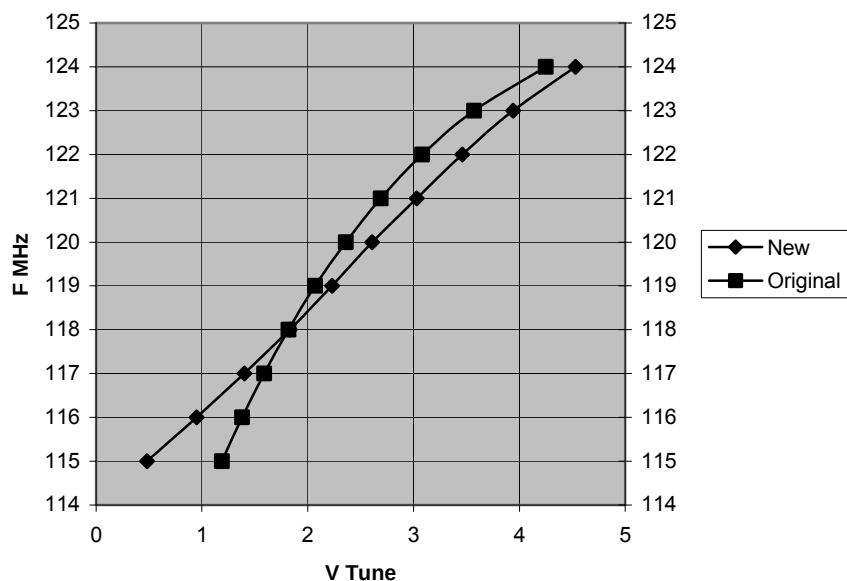


Figure 5 - Comparison of tuning between the original and revised resonator circuits

Frequency (MHz)	Phase Noise at 6.25kHz (original)	Phase Noise at 6.25kHz (revised circuit)
117	-108.9 dBc/Hz	-115.2 dBc/Hz
120	-110.8 dBc/Hz	-113.7 dBc/Hz
123	-113.6 dBc/Hz	-112.6 dBc/Hz

Table 9 - Comparison of RxA VCO phase noise performance

The revised circuit has considerably improved phase noise at the bottom of the tuning range (6dB at 117MHz) but is about 1dB worse than previously at the top end. This is due to the change in Kv slope across the band. It can be observed that the original oscillator had a lower Kv at the top end of the band. The improved adjacent channel rejection performance is shown in the table below. The 70dB specification limit is now exceeded across the entire marine band.

Frequency (MHz)	ACR @ +25kHz	ACR @ -25kHz
156.025	0% PER @ 70dB 16% PER @ 76dB	% PER @ 70dB 17% PER @ 76dB
159.025	2% PER @ 70dB 14% PER @ 74dB	0.2% PER @ 70dB 17% PER @ 74dB
162.025	1% PER @ 70dB 19% PER @ 72.5dB	4% PER @ 70dB 19% PER @ 72.5dB

Table 10 - RxA ACR performance with modified VCO

Note that screening of the RxA VCO circuit is necessary to achieve optimum phase noise performance. This is due to the proximity of the RxA VCO to the CMX7032 circuitry.

5.2 Receiver B VCO changes

5.2.1 RxB VCO trimming

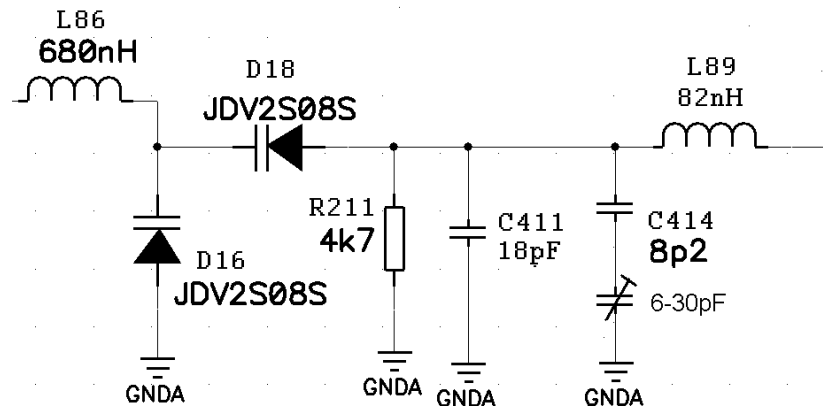


Figure 6 - Addition of a trimmer capacitor in RxB VCO

With reference to the DE70321 schematic:

- C411 remains at 18pF.
- C414 changes from 5.6pF connected to ground, to a 8.2pF capacitor in series with at Murata TZC3P300A110B00 6.5pF to 30pF trimmer capacitor.

5.2.2 RxB Phase Noise improvements

The following modifications have also been shown to improve phase noise at 25kHz by approximately 2dB. These changes use values already on the bill of materials. This increases the current drawn by the VCO stage by approximately 2mA.

- R277, change from 4k7 to 1k8.
- R283, change from 4k7 to 1k8.
- R282, change from 100R to 68R.
- C249, change from NF to 100nF.

5.2.3 RxB VCO tuning characteristics – parallel resonator.

These changes would improve the adjacent channel rejection, limited by phase noise. This may be required for AIS class A applications where performance must be maintained across the whole marine band. The existing design is sufficient for Class B or Rx Only applications.

Note that this shows the original circuit and does not incorporate the modifications of earlier sections. Incorporating both these and earlier LO enhancements would results in exceptional phase noise performance across the whole marine band. Including trimming components into the parallel resonator circuit would require changes in values.

The RxB VCO is designed to cover 126.770 to 132.770 MHz within a tuning voltage range of roughly 1V to 4V (i.e. 156.025-162.025 MHz less the 29.255 MHz IF). The circuit of the VCO is identical in architecture to that of receiver A.

In the original circuit, the VCO gain K_v again varies considerably with a much higher slope at the bottom of the band. Like RxA, the increased K_v results in degraded phase noise performance.

The VCO was changed to use a parallel resonator as follows:

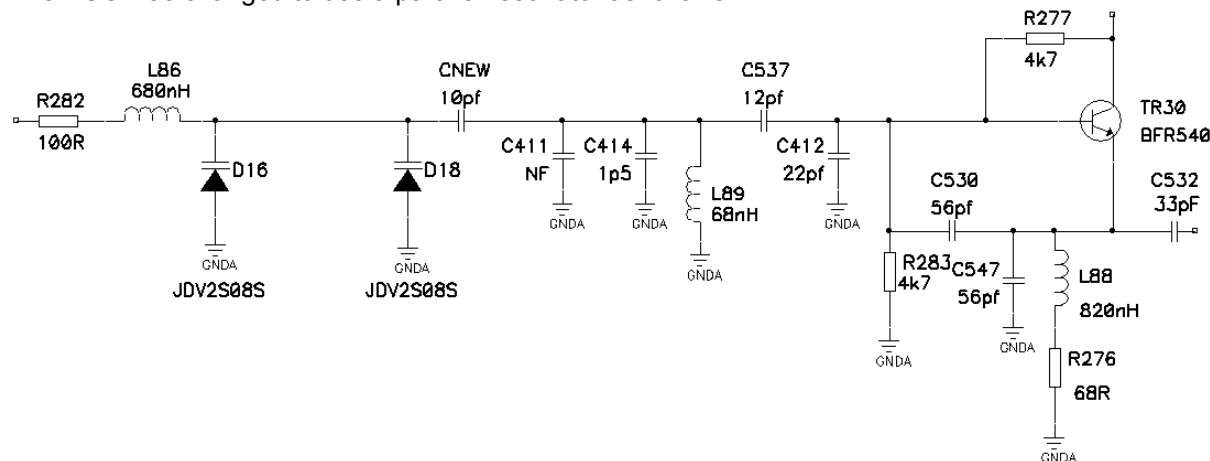


Figure 7 - Rx B 'parallel' resonator circuit

Frequency (MHz)	Vtune	Output Power via buffer amp (dBm)	Phase Noise at 25kHz (revised circuit)
126.52	1.50	12.60	-126.8 dBc/Hz
129.77	2.88	12.45	-126.0 dBc/Hz
132.77	4.43	12.20	-125.7 dBc/Hz

Table 11 - Modified Rx B VCO performance

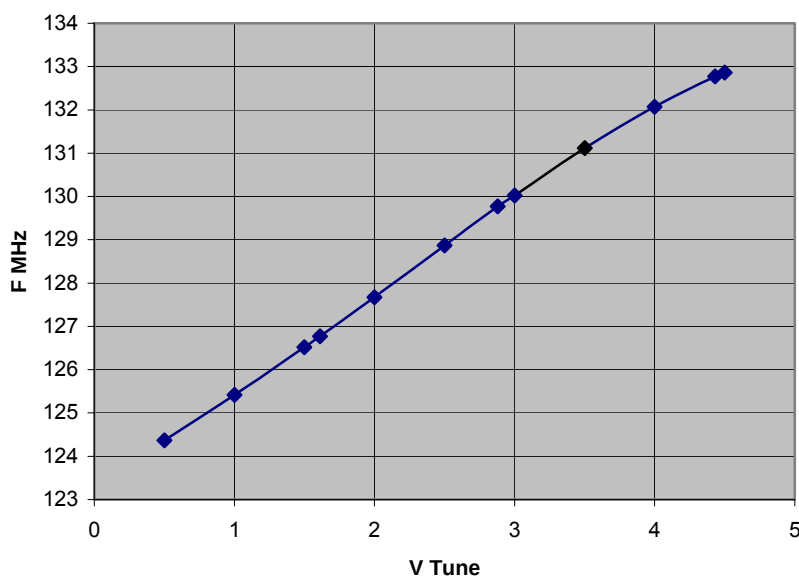


Figure 8 - Modified RxB VCO frequency against tuning voltage

The VCO gain is then consistently between 2 MHz/V to 2.2 MHz/V across the band. Output power is flat to 12.4dBm $\pm$ 0.5dB. As can be seen, the phase noise was improved by around 5dB at the bottom of the band and varies much less.

Frequency (MHz)	Phase Noise at 6.25kHz (original)	Phase Noise at 6.25kHz (revised circuit)
126.77	-109.2 dBc/Hz	-114.8 dBc/Hz
129.77	-111.6 dBc/Hz	-114.0 dBc/Hz
132.77	-113.7 dBc/Hz	-113.7 dBc/Hz

Table 12 - Comparison of Rx B VCO phase noise performance

The improved adjacent channel rejection performance is shown in the table below. The improvements provide margin over the 70dB specification limit across the entire marine band.

Frequency (MHz)	ACR @ +25kHz	ACR @ -25kHz
156.025	0% PER @ 70dB 16% PER @ 74dB	0% PER @ 70dB 19% PER @ 74dB
159.025	2% PER @ 70dB 17% PER @ 73dB	2% PER @ 70dB 12% PER @ 72dB
162.025	0% PER @ 70dB 13% PER @ 73.5dB	0% PER @ 70dB 10% PER @ 73.5dB

Table 13 – Typical Rx B ACR performance with modified VCO

5.3 Rx PLL synthesiser replacement

The LMX2332 is part of a 'family' of dual PLL synthesisers produced by National Semiconductor. It is used in the transceiver version of the DE70321 (DE70321T) to lock the receiver VCOs when the CMX7032 PLL is used for transmitter operation. The LMX2332 family is now obsolete.

Analog Devices offer a substitute pin and software compatible 'family', the ADF421x series, the nearest equivalent to the LMX2332LTM being the ADF4216BRU. Both parts have upper frequency limits of approximately 1.2GHz for the RF PLL and 550MHz for the IF PLL.

Although the devices appear to be very similar, there is one important difference.

The LMX2332 RF synthesiser has selectable prescaler ratios of 64/65 or 128/129.
The ADF4216 RF synthesiser has selectable prescaler ratios of 32/33 or 64/65.

Other members of the ADF421x series have inverted polarity for the RF prescaler control bit.

The result of this is that any code for programming the LMX2332 'RF N' register will have to be re-written for use with the ADF421x family. Use of other registers remains the same.

Results using an ADF4218L (the 2.5GHz version) were as follows:

	5kHz Comparison frequency spur	Phase noise @ 3.125kHz	Phase noise @ 6.25kHz	Phase noise @ 25kHz
RxA VCO 123.17MHz	-84dBc	-105dBc/Hz	-111.6dBc/Hz	124.7dBc/Hz
RxB VCO 132.72MHz	-76dBc	-108dBc/Hz	-113.7dBc/Hz	-127.6dBc/Hz

Table 14 - Rx LO noise using ADF6218 PLL IC

These results are very similar to those obtained on the same board using a LMX2332. In conclusion the Analog Devices ADF4216 is a suitable pin-compatible replacement for the LMX2332 in the DE70321(T).

The Fujitsu MB15U36 has also been tried, successfully, as a replacement to the LMX2332 in the DE70321. Pin 9 must be isolated to disconnect the OSCout pin from ground. Minor host program changes are also required as the MB15U36 uses 64/65 or 128/129 prescaler values for both the IF and RF sections.

5.4 Other receiver issues

5.4.1 Receive mixer diodes

Two BAS70-04 dual Schottky diodes are used in each receiver mixer (D1, D2, D4, D5). Parts by NXP, Infineon (marked '74s') and ST (marked 'D96') are known to perform well, as does the BAT17-04 diode (Infineon marking '54s'). The use of other generic dual Schottky diodes has been known to result in high insertion loss and thus poor sensitivity (typically 5dB lower). Manufacturers are advised to check the mixer performance before committing to using diode types other than those specified above.

5.4.2 Receiver DC level adjustment

It has been noted that the dc level output from the SA58640 IF IC can vary between batches by approximately +/-200mV, independent of any differences in the absolute values of the discriminator / resonator circuit.

The output of the SA58640 is configured as a non-inverting amplifier with a gain of 2. The output from this then drives the CMX7032 input amplifier, which has a gain of approximately 4.5. This gain is needed to provide the minimum peak to peak data levels for the CMX7032 to give optimum performance. Variations in the dc level however (due also to tolerances of the resonator components, temperature, etc.) may mean that the level out of this gain stage at TL7 / TL8 begins to clip against the supplies.

To overcome without changing the AC levels, the following may be implemented.

A resistor (locations R209 and C131, 150k) is normally connected from the input of the CMX7032 op-amp to ground to provide a dc bias. This resistor can be replaced by 100k connected from the CMX7032 input to the output of a DAC (e.g. an AuxDAC of the CMX7032). The DAC can then be programmed accordingly to centre the dc level.

For manual adjustment, or where 7032FI-2.x is used, this point may alternatively be connected to the wiper of a 10k potentiometer connected from the 3.3V analogue supply to ground. The potentiometer can then be adjusted for the optimum dc input level. This adjustment is only necessary at production test.

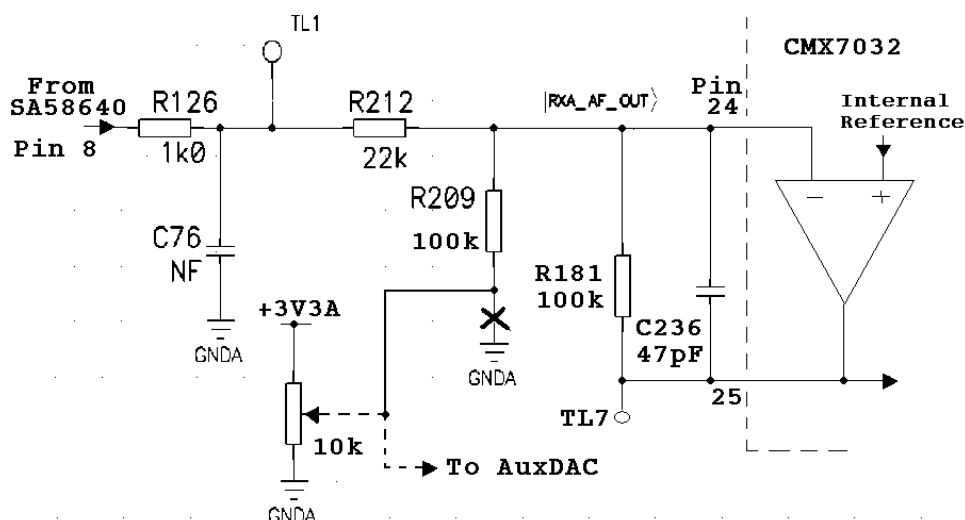


Figure 9 - Modifications to adjust the receiver dc bias into the CMX7032 (RxA shown)

Either of these alternatives are difficult to implement on the DE70321, so where necessary R166 or R213 (which set the SA58640 output level) may be fitted with a value other than 10k.

5.5 Receive only sensitivity enhancements

To improve sensitivity of the DE70321 from around -112dBm to typically -115dBm for less than 20% PER in receive only applications, the following modifications can be performed. The user is referred to the DE70321 schematic [2].

DE70321 Schematic, Sheet 1

Sheet 1

Replace the resistive splitter with the Wilkinson splitter values described.

Component reference	Previous value	Revised value
R11, R4, R13	12R	Not Fitted
R11	12R	0R
C13	Not Fitted	27pF
L6, L7	Not Fitted	68nH
R8	Not Fitted	100R
C6, C12	Not Fitted	12pF

LNA gain enhancement

Component reference	Previous value	Revised value
R16	4R7	6R8
R17	Not Fitted	6R8

Sheet 2, 4

A minor improvement in co-channel performance may be achieved by using a wider bandwidth second 455kHz filter (CD3, sheet 2 and CD3, sheet 3).

Two cascaded filters are used around the SA58640 IF IC. The receiver selectivity is dominated by the receiver 1st LO phase noise, nominally 15kHz bandwidth. The second filter is used to provide band-limited gain to the IC (over 100dB of gain at the 2nd IF), keeping the receiver stable. This second filter may be changed from an 'E' bandwidth to a 'B' bandwidth (30kHz) type with little change in adjacent channel performance. PER levels at the co-channel

test limit are improved by a few percent due to the small reduction in group delay distortion from the wider filter.

Sheet 5

To bypass the transmitter harmonic filter and PIN diode switch, remove C177, C215, C226, L13 and L16. A short wire link is then added between the pad of C117 and C226. In total these modifications reduce the losses in the receive path by several dB and also increases the LNA gain by approximately 1dB resulting in the improvement in sensitivity.

6 Transmitter recommendations

6.1 Tx modifications

6.1.1 Tx VCO trimming

The following modifications detail how a trimmer capacitor may be added to a user's implementation to allow adjustment of the Tx VCO tuning voltages in production. With reference to the DE70321T schematic:

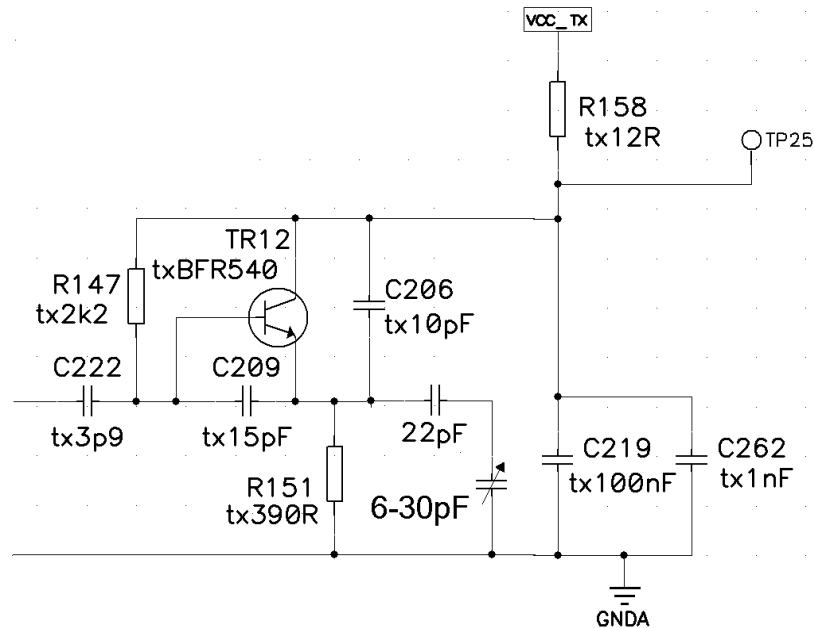


Figure 10 - Modifications to the TxVCO schematic to incorporate a trimmer

- C206 changes from 15pF to 10pF.
- A new 22pF capacitor is connected from the TR12 emitter / C206 junction to a Murata TZC3P300A110B00 6.5pF to 30pF trimmer capacitor.
- The other end of the trimmer capacitor is then connected to ground.

These modifications result in almost identical tuning sensitivity but allow approximately $\pm 0.35V$ adjustment to the tuning voltage.

6.1.2 Tx VCO buffer output/divider input

These enhancements improve the transient behaviour of the transmitter during the rising and falling edges of the AIS transmitter burst.

Two modifications are recommended to the Tx VCO buffer and divider input area of circuitry. Additionally, changes are required to the Tx PLL loop filter.

The feedback from the VCO buffer amplifier to the CMX7032 PLL input needs to be increased to overcome interference that may be experienced from C-BUS communications. This may be observed as occasional 'glitches' in the de-modulated FM waveform. The modification involves taking the feedback from the collector of the VCO buffer amplifier (TR13) instead of the emitter.

- Lift the emitter of TR13 and R153.
- Connect the TXVCOFB line to TR13 collector via a new 100 ohm resistor.
- Re-connect TR13 emitter to ground via a 4R7 resistor (replace R153).

The TXVCOFB line is now connected to the collector and not the emitter (It may be easier to remove TR13 temporarily to perform this mod).

TR13 should also be presented with a more consistent load to prevent frequency transients due to the switching on and off of the divider IC (U10). To do this, perform the following modifications:

- Lift the U10 end of C207. Keep the other end connected to TR13.
- Fit a new 15pF capacitor from C207 to U10 pin 2 (so the two capacitors are in series).
- The supply resistor to U10 (R169) can be changed from 0R to 47R if additional decoupling is required.

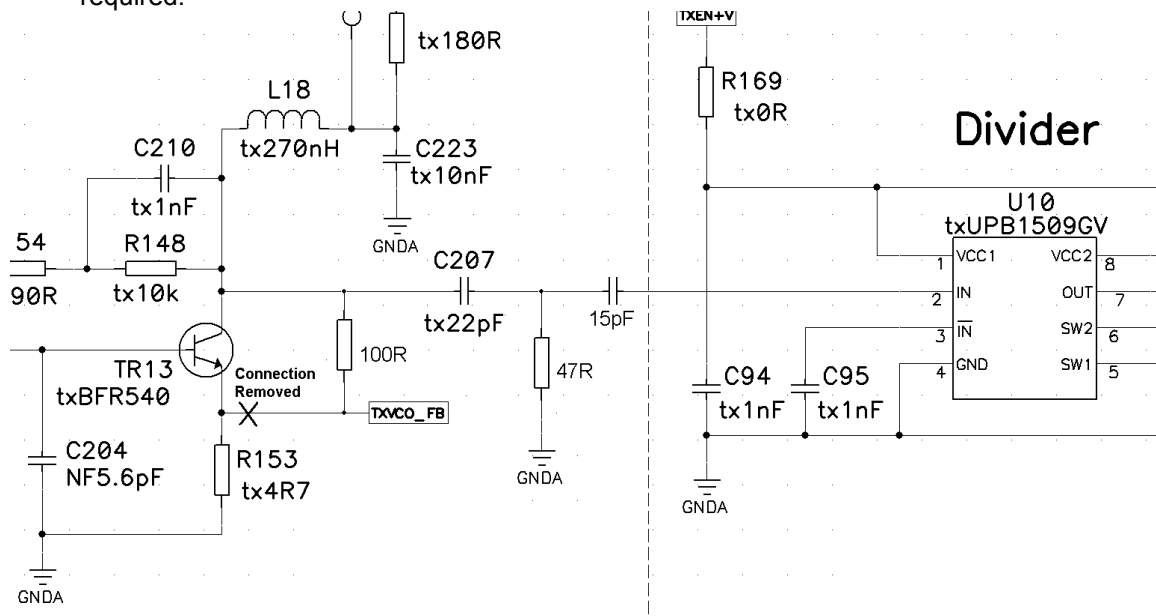
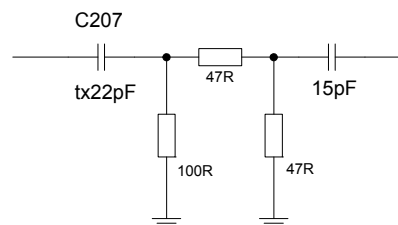


Figure 11 - Transmitter VCO buffer / divider input modifications

- Add a 47R resistor from the middle of the capacitors to ground. Further improvement may be made in the frequency transient response by implementing this termination as an attenuator. This provides the same load to the VCO buffer but provides approximately 6dB more isolation from changing load conditions. See side figure.



The transmitter loop filter also requires modification to increase the damping and increase the bandwidth slightly. Note that the original values are those used for the CMX7032 to lock the receiver VCO's in a 'receive only' application. These changes are only required in a transponder / transmitter implementation.

- R157 was 0R change to 2k2
- C216 was 1n0 change to 10nF
- R196 was 820R change to 1k8
- C235 was 68n change to 22nF

The μ PB1509GV divider input is sensitive down to approximately -35dBm at around 300MHz so there still is plenty of input drive after these modifications have been completed.

6.1.3 Power amplifier

A minor change to the transmitter power amplifier may also be made.

It has been found that inductor L11 (a 10R impedance ferrite) in the RF power amplifier section is run over its absolute maximum current rating. This can be replaced with a 0R 0402 resistor with no noticeable change in performance.

6.1.4 RAMDAC table

The transmitter spectrum is related to the PA ramping profile. This can be changed by re-writing the RAMDAC table. As users of the CMX7032 / CMX7042 may choose to use a different PA to that used in the DE70321, the table values may need to be adapted to suit a particular implementation and system gain to achieve the correct output power. It is difficult therefore to guarantee performance with a particular set of RAMDAC values and it is likely that the default table values, whilst providing a useful starting point for development, will not be suitable. A ramp table based on a truncated SINC response has proved usable with the DE70321T and is shown in Table 15.

RAMDAC table location	SINC response RAMDAC Values							
0-7:	0000	0100	0200	0300	0350	0375	0425	0469
8-15:	0475	0481	0487	0494	0500	0506	0512	0517
16-23:	0523	0529	0534	0540	0545	0551	0556	0561
24-31:	0566	0571	0576	0581	0585	0590	0594	0599
32-39:	0603	0607	0611	0615	0619	0623	0626	0630
40-47:	0633	0636	0639	0642	0645	0648	0650	0653
48-55:	0655	0657	0659	0661	0663	0665	0666	0668
56-63:	0669	0670	0671	0672	0673	0674	0674	0675

Table 15 - Alternative RAMDAC values for the DE70321T based on a SINC response

7 Transmitter system performance

7.1 Continuous output

The following plots (Figure 12, Figure 13, Figure 14) show the performance of the complete transmitter during continuous modulation conditions.

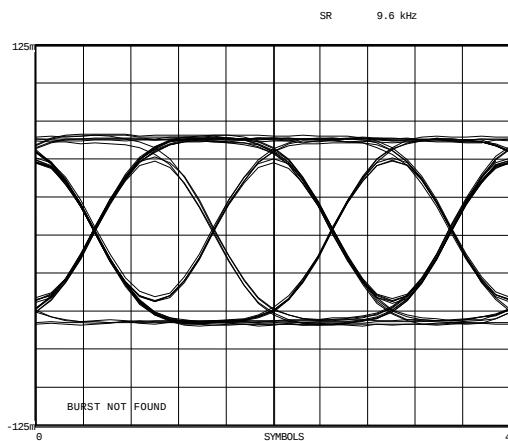


Figure 12 - Tx eye diagram

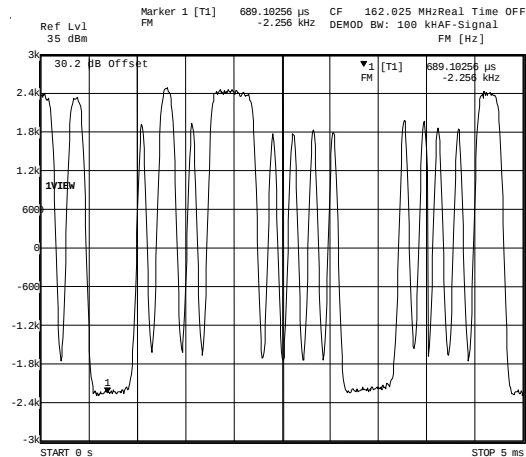


Figure 13 - Tx deviation plot

Figure 12 and Figure 13 show that the deviation is clean and relatively symmetrical, given that in these plots no fine-trim of operating frequency has been made (the unit is slightly high in frequency). The lower limit of deviation is around -2.26kHz.

The output of the transmitter was tested via a power attenuator into a spectrum analyser as shown in Figure 14.

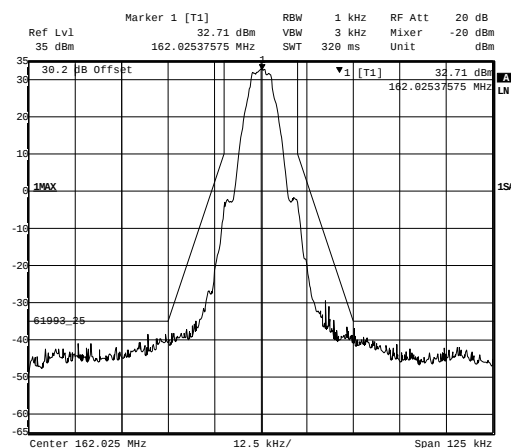


Figure 14 - Tx Spectral mask at the PA output, +33dBm, 162.025MHz, continuous PRBS, against AIS class A mask (-70dB)

Note that the mask limit shown is that of the Class A standard, IEC61993-2, for continuous transmission (-70dBc). The Class B standard is -60dBc but with the transmitter operated in burst / slotted mode, so transmitter ramp-up and down transients apply.

7.2 Packet 'slotted' transmission

The following plots show the performance of complete transmitter with normal packet ('Slotted') transmission after the modifications described herein.

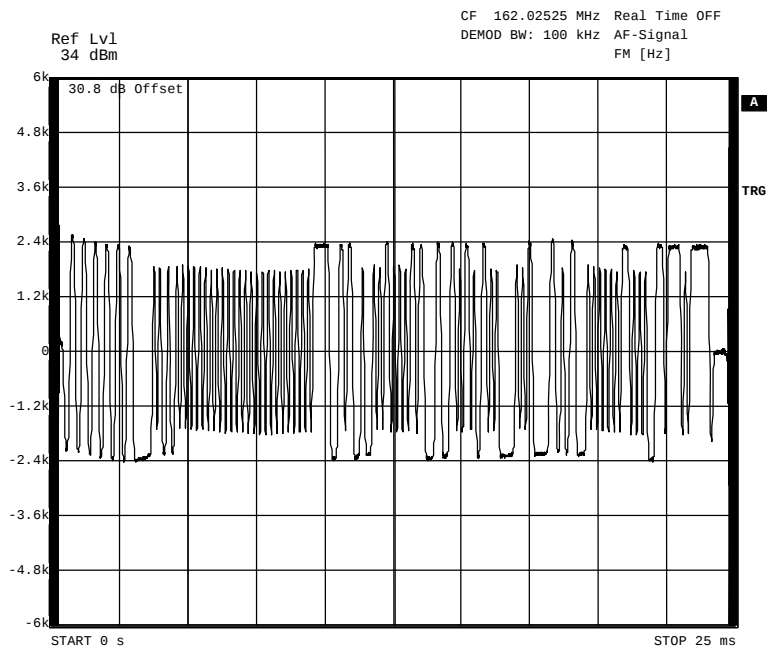


Figure 15 - Modulation vs time profile

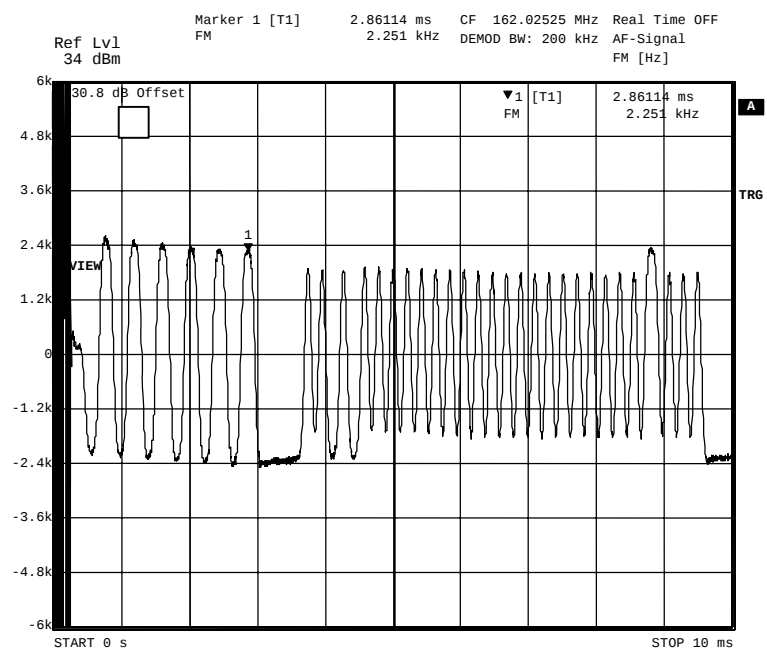


Figure 16 - Modulation plot, start of burst.

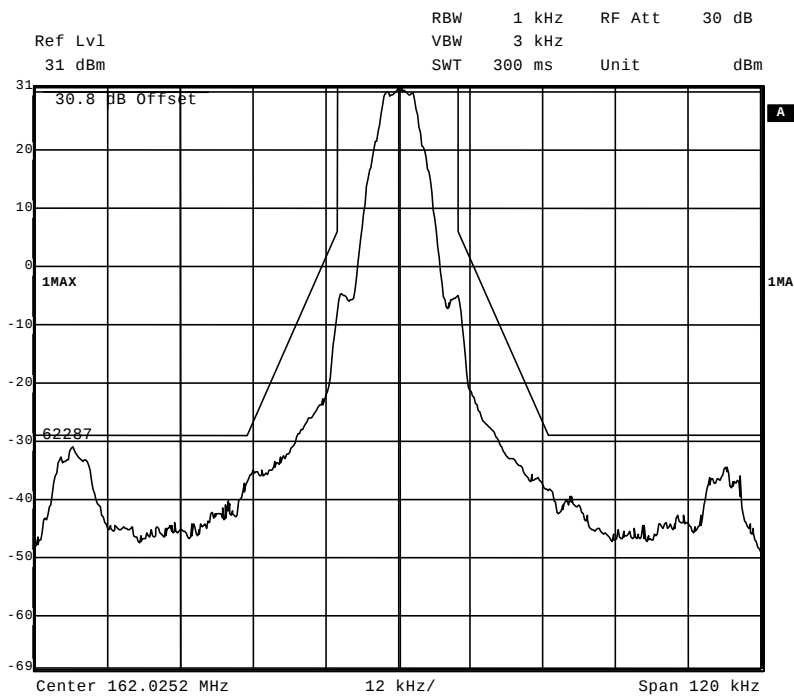


Figure 17 – DE70321 AIS Class B (IEC62287) spectrum mask with bursts (max hold)

7.3 References

- [1] IEC62287- Class B shipborne AIS using CSTDMA techniques. ☐
- [2] DE70321 – CMX7032 AIS demonstrator schematic, version B05.
- [3] CML Application Note 'DE70321 System Level Tests', Issue 2, November 2008

Annexe A Identifying the mod state and board revision

The mod state (modification state) of the DE70321 can be determined from the 'Board Mod' box printed on the PCB silkscreen. The highest number in the box that is blacked out gives the mod state. The following examples indicate a mod state of 3.

Board Mod			
●	●	●	4
5	6	7	8

Board Mod			
●	●	●	4
5	6	7	8

Figure 1. Examples of how the mod state box may look

The letter that follows the PCB reference gives the board revision. The DE70321 will be marked "PCB70321B" indicating that the board is revision B. The first production release was PCB70321B mod state 3.

8 Annexe B – Earlier Enhancements to DE70321/DE70321T

8.1 B.1 Mod state 4 or below:

A possible SPI conflict exists when the LMX2332 is fitted but not powered and the C-Bus option is enabled. There is provision for isolating resistors to be fitted. 1k resistors should be fitted at these points:

- Change R100 from 0R to 1k0
- Change R131 from 0R to 1k0

Both resistors are located on the underside of the PCB, close to the LMX2332 (U8).

8.1.1 B.1.1 Receiver DC Coupling

An extract from [2] giving the circuit of the receiver A output is shown in Figure 2.

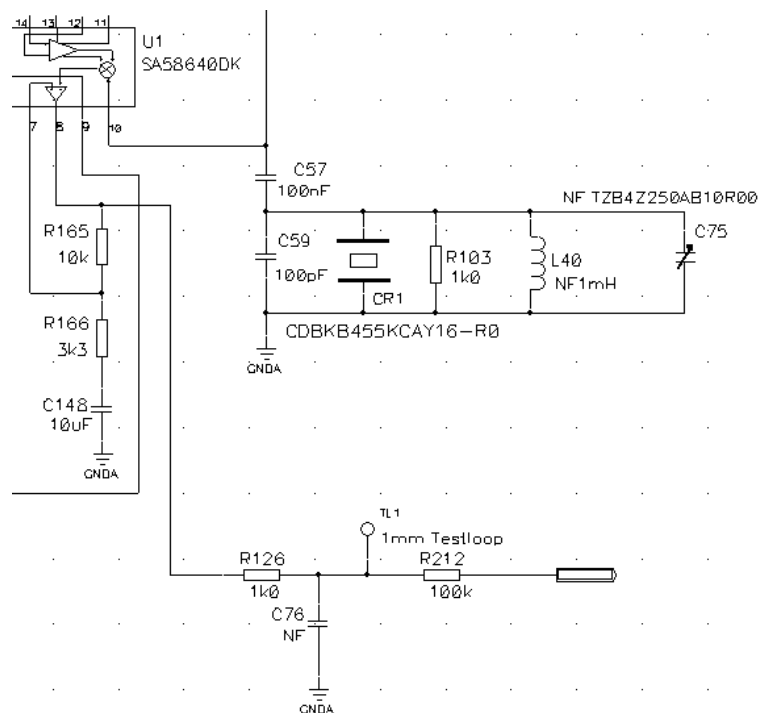


Figure 18 - The original RXA output circuit

In the original circuit, R165, R166 and C148 form a non-inverting op-amp (using pins 7 and 8 of U1), having gain and a low-frequency response down to below 5Hz. Resistors R126 and R212 form the input resistor to a unity gain inverting op-amp with a low pass filter (the output end of R212 is pin 24 of U27, the CMX7032, Rx1IN).

The dc level from demodulated noise (no carrier present) can be different to the dc level from a demodulated signal and so a transient response is produced. In this case the CMX7032 may fail to successfully decode due to the change in dc level across the packet. The transient will be more pronounced if frequency offsets are also present.

To eliminate the transient and improve performance, the circuit can be modified to dc couple the output from U1, applying the necessary gain and dc shift with the CMX7032 input-op-amp. The modifications can be implemented as follows:

- R166 change from 3k3 to 10k.
- C148 change from 10uF to 0R (NB: Resistor or wire link).
- R212 change from 100k to 22k.
- Add a new 150k resistor from the output end of R212 / Inverting input of the 7032 (pin 24) to ground. This is most easily added near R212.

Receiver B improvements

An extract from [2] giving the circuit of the receiver B output is shown in Figure 19.

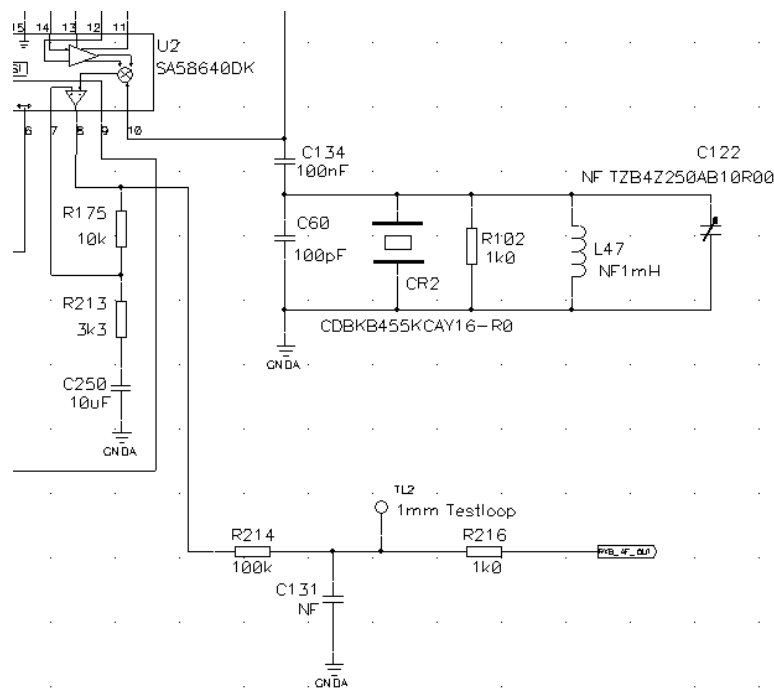


Figure 19 - The original RXB output circuit

The circuit is identical in architecture to that of receiver A. The following changes are required to implement dc coupling:

- R213 change from 3k3 to 10k.
- C250 change from 10u to 0R (NB: Resistor or wire link).
- R214 change from 100k to 22k.
- Add a 150k resistor at C131 (currently Not Fitted).

The output end of R216 is the input to the inverting op-amp of the CMX7032 (Rx2IN, pin 26). Note that the order of the two input resistors is different to receiver A. This is due to a previous modification and the differences in layout and resistor locations between the two receivers. For ease of implementation, the new 150k resistor can be inserted at the C131 location and not applied directly to the inverting input as in RxA. As the intervening resistor (R216, 1k0) is small in value compared with the rest of the op-amp values, there is negligible difference in practice between the two implementations.

8.1.2 B.1.2 VCTCXO Tuning Improvement

For transponder applications, when transmitting, the VCTCXO (U25) requires a dc coupled modulation signal to be applied to its tuning input. In receiver mode this output would be set to an appropriate dc level (e.g. VBIAS) via C-BUS register control.

For receive only applications using FI-2 (default configuration of DE70321), the voltage presented to the VCTCXO tune input (typically 1.2V) is not optimum and gives around -500Hz frequency error. This error can be reduced by connecting the VCTCXO tune input to the Vbias voltage. To do this, the circuit should be modified as follows:

- Remove R184
- Add a link to connect the C239 / TL9 node to V_{BIAS} / C31 (pin 33 of the CMX7032), as shown in Figure 20.

C31 is located next to R184 as can be seen in the extract from the layout below.

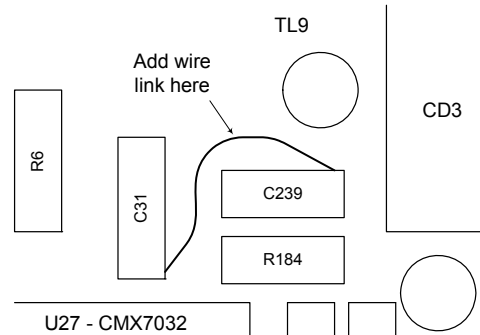


Figure 20 - VCTCXO tuning modification

8.2 B.2 Mod State 3 and Below

The DE70321 AIS Demonstration Kit may be enhanced by dc coupling the IF demodulator integrated circuit audio outputs to the CMX7032 inputs. For PCB Mod State 3 and below these are low-frequency ac coupled.

A further modification to the VCTCXO control line may also provide improvements in receive only applications.

The changes have been found to improve the performance of the receiver in certain circumstances and in some cases with discontinuous AIS bursts the improvement is significant. It is recommended that all users of the DE70321 with units of mod state 3 or earlier implement these changes

8.3

8.4 B.3 Errata

8.5

On high resolution schematic Dwg70321b02.pdf

- R126 shown as 1k0 in the schematic, should be 100k
- R214 shown as 1k0 in the schematics, should be 100k

9 **Annexe C** **Glossary of terms**

ACR	Adjacent Channel Rejection
AIS	Automatic Identification System
CSTDMA	Carrier Sensed, Time Division, Multiple Access.
IF	Intermediate Frequency
LO	Local Oscillator
PER	Packet Error Rate
PLL	Phase Locked Loop
RF	Radio Frequency
Rx	Receiver
RxA	Receiver Channel A
RxB	Receiver Channel B
Tx	Transmitter
VCO	Voltage Controlled Oscillator

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Tel: +44 (0)1621 875500 Fax: +44 (0)1621 875600 Sales: sales@cmlmicro.com Tech Support: techsupport@cmlmicro.com	Tel: +1 336 744 5050 800 638 5577 Fax: +1 336 744 5054 Sales: us.sales@cmlmicro.com Tech Support: us.techsupport@cmlmicro.com	Tel: +65 67450426 Fax: +65 67452917 Sales: sg.sales@cmlmicro.com Tech Support: sg.techsupport@cmlmicro.com
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