Components for modular microwave transverters

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Content

- Multiband transverter systems
- Filters and multiplexers
- PLL-disciplined oscillators
- Transverters
- 2320 MHz transverter core
- 5760 MHz transverter core
- Further modules (planned)
- Conclusion
Multiband TVTR systems

- Multiband transverter systems
- Filters and multiplexers for multiband operation
- PLL-disciplined oscillators
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Single band transverter

- Single band single box transverter: all you need in one box, plus an external low gain PA
Multiband TVTR example 1

Multiple TVTRs each with PA in the tower

IF TRX (1 switched or multiple)
Multiband TVTR example 2

Multiband TVTR with PAs in the shack, RX preamps in the tower.
Wideband feedhorn.
Shack or Tower - what goes where?

- **RX preamp and T/R-switch:**
  - in the tower or even in the feed

- **PA and PSU:**
  - Solid state PA in the tower, PSU in the tower or shack
  - TWT in the shack/attic oder in the tower
  - Drive power typically 0…+10 dBm

- **Transverter:**
  - in the shack: environmentally stable, vibration free, easily accessible for service, 10 MHz easily available
DF9ICs planned multiband TVTR

Multiband TVTR in the shack, all PAs and RX preamps in the tower

One coaxial cable + one DC cable to the tower
Requirements for the TVTR core

- RX amp: low gain and sensitivity
- TX amp: low output power (+5…+15 dBm)
- LO:
  - Low spurii and low noise
  - 10 MHz input for OCXO/GPS lock
- IF interface:
  - Switchable to each band
  - IF TX power up to 25/50 W
  - 2 RXs in same or on different bands
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Multiplexer for 23/ 13/ 9/ 6 cm
**Multiplexer?**

- Several microwave signals over one cable at the same time
- 23 cm, 13 cm, 9 cm, 6 cm
- RX or low power TX (<1 W)
- Decent insertion loss (ca. 1 dB) and isolation (>20 dB)
- Microstrip on RO4003 substrate, e. g. no-tune
- For use in multiband TVTR systems
Multiplexer: possible structures

- **Star topology:** difficult

- **Cascaded drop filter topology:**
Multiplexers: basic element

- Bandpass drop and lowpass through

![Diagram showing a multiplexer with λ/4 sections and Tiefpass and Bandpass labels.]
Multiplexer: PCB layout

- 3 elements cascaded and folded
Multiplexer: optional Bias-T

- application:
  - signalling or telemetry
  - (only small currents!)

![Diagram with symbols and values: 1 nF, 470 nH]
Multiplexer: bandpass 5760 MHz
Multiplexer: bandpass 3400 MHz
Multiplexer: bandpass 2320 MHz
Multiplexer: lowpass 1296 MHz
More microstrip filters designs

• No-tune filters for simultaneous operation on 1296 and 2320 with dual band feed
  o Lowpass filter 1296 MHz with bandstop 2320 MHz
  o Highpass filter 2320 MHz (needs discrete capacitors)
  o Alternate solution: Bandstop filter 1296 MHz with bandpass 2320 MHz

• Printed microstrip on RO4003 substrate

• Can be used for RX or low power (10 W) TX
Lowpass 1296 with bandstop 2320
Bandstop 1296 with bandpass 2320
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Precise frequency helps for QSOs

• How much do we need for a sked?
  o 1296 MHz: $10^{-7}$ means 130 Hz error
  o 10 GHz: $10^{-8}$ means 100 Hz error
  o 122 GHz: $10^{-9}$ means 120 Hz error

• Various levels of temperature stability:
  o XO: $10^{-5} \ldots 10^{-6}$
  o Amateur VHF OCXO: $10^{-6} \ldots 10^{-7}$
  o Professional OCXO: $10^{-7} \ldots 10^{-10}$

• Ageing: about $10^{-7} \ldots 10^{-8}$ per year
Frequency standards available

- Commercial surplus GPS disciplined standard, e.g., HP Z3801A
- Also Rb standards

- Amateur GPS disciplined standard, e.g., G3RUH

- OCXOs (standalone for portable operation)
10 MHz distribution amplifier

MAX 4022 (quad video buffer) with lowpass filter at the input

5 V regulator included, max. 100 mA

Input/output 50 Ohm @ max. +5 dBm
Retrofit of existing transverters

- Standard LO chain

- with OCXO

- with PL-VCXO
Phase-locked VCXO (PL-VCXO)

- Short term stability (phase noise) of ordinary crystal oscillator
- Long term stability determined by external frequency standard
- Tuning range of VCXO must be sufficient to compensate temperature influence and ageing
Basic XO circuit

Similar to DB6NT XO and others:

- RC lowpass in the supply voltage filters voltage regulator noise
- Careful compensation of the static capacitance of the crystal is needed

Now we add the tuning network and a buffer stage
VCXO circuit

Component values for 100 MHz:

- C5 22 pF
- C6 68 pF
- L3 470 nH
- L6 + L7 ca. 300 nH (total)
Varicaps

BB814

Twin varicap for FM radios

Diode capacitance \( C_T = f(V_R) \)
\( f = 1\,\text{MHz} \)
Transfer function tuned crystal

\[ U_a = 2.5 \, \text{V} \]
Transfer function tuned crystal

U_a = 0.5 V

U_a = 4.5 V
Oscillator tuning \( (f_0 = 100 \text{ MHz}) \)
Integrated PLL circuit
Complete circuit of PL-VCXO

PL-VCXO
DF9IC 1/2008

31. Nordic VHF Meeting 2009 Kottebo
Wolf-Henning Rech DF9IC

IC1
78L08

IC2
78L05

VCXO out
typ. +3 dBm

+12 V
<100 mA

D4
BAT42

C1 2,2n

R1 100

C6 siehe Text

L1 Neosid 5061

T1 J310

R2 100

C2 10μ

C3 2,2n

L2 2,2μ

C4 2,2n

Quarz siehe Text

L3 siehe Text

C7 220p

C8 2,2n

R6 4,7M

C9 2,2n

R7 100

T2 J310

L6 siehe Text

R3 10k

R4 10k

C10 100n

L7 siehe Text

R5 10k

L4 2,2μ

D1 BB814

R10 1k

10 MHz

Vcc

1 Vss
50MΩ

R11 100

C10 100n

C11 100n

C12 2,2n

T3 J310

R8 100

C13 2,2n

D3 BB814

L8 2,2μ

C14 100n

C15 100n

R12 100

R13 1k

D5 LED

R14 1k

D6 LED

8 Kodierbrücken
zur Konfiguration

IC3
ADF4110/4111

IC4
PIC16F648A
Construction of PL-VCXO
Spectrum (harmonics)
Spectrum (Spurii +/- -12.5 MHz)

Date: 7.FEB.2008 07:55:57
Spectrum (Spurii +/- 5 kHz)

Date: 7.FEB.2008  08:27:21
Transient behaviour

Measured with HP5371A
DUT locked to the HP5371A internal OCXO
Frequency: 100 MHz
Sample time: 100 ms
Resolution: ca. 3 E-9

# of measurements: 100
PL-VCXO frequency stable after a few seconds
Frequency jitter

Measured with HP5371A

DUT locked to the HP5371A internal OCXO

Frequency: 100 MHz
Sample time: 2 s
Resolution: ca. 1.5 E-10

# of measurements: 100

All measurements are within +1 digit around the nominal value
Phase noise (simulation)

Simulation with ADISimPLL (Analog Devices)

Measurement with R&S FSUP here in Knottebo
\[ \text{PLLO} = \text{PL-VCXO} + \text{multiplier} \]

\[ f_{\text{out}} = 900 \ldots 1300 \text{ MHz} \]
PLLO design criteria

- VHF-XO + multiplier for best phase noise
  1-100 kHz off the carrier, PLL disciplined XO
- Flexible multiplying and output frequencies
- Few standardized special components

- Passive symmetrical doubler as 1st multiplier
- GALi MMICs as active components
- Helix filter for output frequency
Frequency multipliers

- 1st multiplier stage: high level Schottky diode doubler

- 2nd multiplier stage: comb generator and helix filter
Frequency multiplier circuit

- **Buffer amplifier**: GALi-6
- **Doubler**: AMK-2-13
- **Comb generator**: GALi-19, GALi-5
- **Filter and amplifier**: Helixfilter Toko 5HW, GALi-33

Input: 950 - 1300 MHz
Output: +10 dBm
Layout PLLO

FR4 1,5 mm  37 x 111
Spectra between stages

- at output of AMK-2: 271.25 MHz -4 dBm
- at output of GALi-5: 1085 MHz +2.5 dBm
Output spectrum

Res BW 1 MHz
Auto Range: Atten: 13 dB  Ext Gain 0.0 dB

10 dB/div Ref 20.0 dBm
Log

10.0

0.0

-10.0

-20.0

-30.0

-40.0

-50.0

-60.0

-70.0

Start 100 kHz
Stop 1.810 GHz

#Res BW 1 MHz VBW 1 MHz Sweep Time: 2.22 s (401 pts)

MKR1: 1.086 0 GHz 10.50 dBm

Output phase noise (PLL OFF)

DB6NT 1.3 GHz TVTR LO: -138 dBc/Hz @ 20 kHz
Result PLLO

- Universal LO chain for various microwave transverters
- PLL to an external frequency standard included
- 55 dB spurious attenuation
- Phase noise -150 dBc/Hz @ 100 kHz for 1 GHz output
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Modular TVTR approach

- (23 cm), 13 cm, 9 cm, 6 cm
- Separate modules:
  - 1 PLLO + 1 TVTR core (frequency translator) for each band
  - Common IF interface for up to 4 transverters and 2 RXs
  - Common control and telemetry board
- Easier development and more flexible than single box transverters
- Disadvantages: size, additional connections
Modular TVTR approach
Multipliers to the final LO frequency

- 23 cm:  1150 MHz $\times$ 1 with 146 MHz IF
  1246 MHz $\times$ 1 with 50 MHz IF
- 13 cm:  1087 MHz $\times$ 2 with 146 MHz IF
- 9 cm:   1084.666 MHz $\times$ 3 with 146 MHz IF
- 6 cm:   934.666 MHz $\times$ 3 $\times$ 2 with 146 MHz IF

- Additional multiplier(s) part of the TVTR core module - needs moderate quality bandpass filter after 1st multiplier (Microstrip on FR4)
FR4 microstrip bandpass filter

3 side coupled λ/4 resonators

Precise contacts to the GND plane by rivets
Bandpass 2200 MHz FR4

Example:

Bandpass for 13 cm
LO frequency

1088 MHz: -37 dB
2176 MHz: -2 dB
3264 MHz: -54 dB

Can be scaled also to 2800 MHz (LO/2 for 6 cm) and 3250 MHz (LO for 9 cm)
Image and LO rejection filters

- Needed both in RX and TX section
- 1296 + 2320 MHz: helix filters available
- 3400 + 5760 MHz: pipecap resonators
Pipecap filters for 3400 and 5760

3400 MHz:
-3.5 dB

(3400-146) MHz:
-30 dB

5760 MHz:
-2.8 dB

(5760-146) MHz:
-27 dB
Requirements for the TVTR core

- RX amp: low gain and sensitivity
- TX amp: low output power (+5…+15 dBm)
- LO:
  - (...)
- IF interface:
  - (...)
- FR4 board and MMIC amplifiers
Active RF components for the TVTRs

- Use of a standardized set of MMICs
- GALi/GVA from MiniCiruits: good GND, good thermal design, easy to solder on PCB
  - GALi 19+ (similar to GALi 1): 10-12 dB gain for RX and small signal TX amp
  - GALi 33+ (similar to GALi 3): 15-20 dB gain for RX and small signal TX amp and multiplier
  - GALi 5+: multiplier, comb generator, amp
  - GVA 84+: medium power amp +20 dBm
- can be exchanged to vary gain and power
Active RF components for the TVTRs

- 7...13 dBm mixers, sometimes available from surplus boards - e.g. WJ SME, MiniCircuits SIM
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Transverter core for 2320 MHz
TVTR 2320: Block diagram

- **RX**: 2-stage amplifier, 2 helix filters
- **TX**: 2- or 3-stage amplifier, 2 helix filters
- **LO**: frequency doubler + bandpass, 10-13 dBm
PCB layout 13 cm transverter

FR4 1,5 mm  55 x 111
Transverter core for 2320 MHz
Spectrum at LO x2

Res BW 1 MHz

Atten: 18 dB  Ext Gain 0.0 dB

MKR1: 2.175 GHz
9.60 dBm

Log
10 dB/div  Ref 20.0 dBm

Start 100 kHz
Stop 5.00 GHz

#Res BW 1 MHz  VBW 1 MHz

Sweep Time: 6.76 s (401 pts)
Spectrum at mixer output
Spectrum at TVTR output

Resolution BW 1 MHz

Auto Range

Atten: 17 dB
Ext Gain 0.0 dB

Trace

Type

Det

Frequency: 2.3200 GHz

10 dB/div
Ref 20.0 dBm

Log

10.0
0.0
-10.0
-20.0
-30.0
-40.0
-50.0
-60.0
-70.0

Center 2.200 GHz

Span 1 GHz

#Res BW 1 MHz

VBW 1 MHz

Sweep Time: 1.19 s (401 pts)

MKR: 2.3200 GHz

18.59 dBm
Results 13 cm transverter core

- Simple construction, FR4 board
- TX: up to 20 dBm at >55 dB spurious attenuation
- RX: 4 dB noise figure and 10 dB conversion gain (with indicated parts)
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Transverter core for 5760 MHz
Transverter core for 5760 MHz

- Modified 13 cm transverter
  - Filters changed from helix to pipecap
  - Extra LO doubler and amplifier
  - T/R Splitter instead of PIN switch
PCB layout 6 cm transverter

FR4 1,5 mm  74 x 111
Spectrum at LO x3

<table>
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<tr>
<th>Marker 2.805 GHz</th>
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<tbody>
<tr>
<td>Auto Range</td>
<td>Atten: 14 dB</td>
<td>Ext Gain 0.0 dB</td>
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<table>
<thead>
<tr>
<th>10 dB/div</th>
<th>Ref 10.0 dBm</th>
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<tbody>
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<td>0.0</td>
<td>-10.0</td>
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<tr>
<td>-70.0</td>
<td>-80.0</td>
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</tbody>
</table>

- Center 3.00 GHz
- Res BW 5 MHz
- VBW 5 MHz
- Span 5.999 GHz
- Sweep Time: 1.45 s (401 pts)

MKR1: 2.805 GHz
5.64 dBm
Spectrum at LO x3 x2
Spectrum at LO input of mixer

Marker 5.625 GHz
Auto Range     Atten: 9 dB     Ext Gain 0.0 dB

10 dB/div     Ref 10.0 dBm

Log

0.0
-10.0
-20.0
-30.0
-40.0
-50.0
-60.0
-70.0
-80.0

Center 3.00 GHz  Res BW 5 MHz  VBW 5 MHz  Span 5.999 GHz  Sweep Time: 1.45 s (401 pts)

MKR1: 5.625 GHz
7.32 dBm
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Further modules (planned)

- 9 cm transverter core:
  like 6 cm, different LO path without 2nd multiplier stage

- 23 cm transverter core:
  LO driver for +17 dBm mixer, 2 stage TX amp, otherwise similar to 13 cm transverter

- IF interface

- Control board and telemetry system

- (PAs and preamps from existing designs)
Conclusion

- A modular approach may suit better the needs of a multiband transverter system for use at home on 23/13/9/6 cm
- Masthead preamps and PAs should be combined with basic transverters in the shack
- Some of the necessary modules have been realized, others are in development or planned