Updated 2-04-2005
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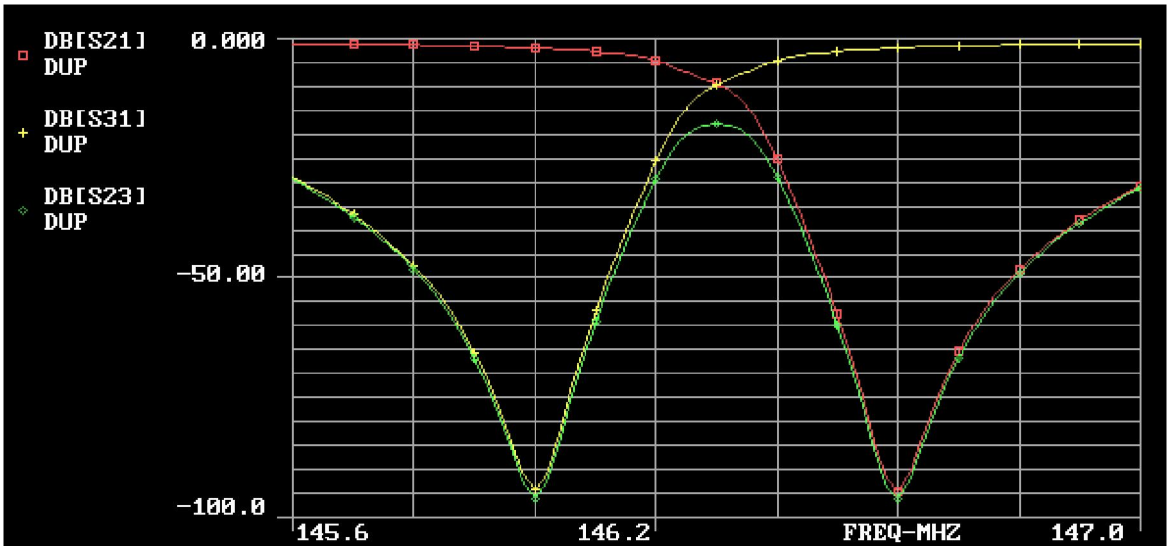
To have a duplexer designed, engineered and custom-built to your specifications which is rugged enough to withstand shipping via UPS, e-mail me (Jim) here: "jvpoll at dallas dot net".

Two Meter Heliax Duplexers



High-band VHF Heliax Duplexer Performance on 2 Meters

Shown above is a graphic displaying the performance of a:

- 600 KHz split,
- 95 dB Isolation,
- 2 dB Insertion Loss,
- 8 stub **Two Meter** Heliax Duplexer
- operating on a 146.000 MHz / 146.600 MHz frequency pair.

This graphic shows the following "S21" S-Parameter sweeps:

1. S21 measurement, measured from the receive port to the antenna port (square/red line --------),
2. S31 measurement, measured from the transmit port to the antenna port (plus sign/yellow line --------) and
3. S32 measurement, the 'isolation' a duplexer exhibits from receiver to transmitter measured from the receive port to the transmit port (diamond/green line ---------).

The Insertion Loss in the 'passband' of this duplexer shows to be under 2 dB. S11 (Return Loss) on each port shows to be over 20 dB on each port (see further below for S11 sweeps).

-- Duplexer Types --

In the world of duplexers, there basically four different types:

a) BP - Band Pass, built using tuned/resonant elements which 'pass' one particular

frequency
b) BR - Band Reject, built using tuned/resonant elements that 'notch' out one particular frequency
c) BPBR - Band Pass Band Reject, a combination of the above
d) HPLP - High Pass Low Pass, built using high pass fitlers and low pass filters.

The duplexer described on this web page **is a *Band Reject*** (BR) type **duplexer** as opposed to a (sometimes more desirable, depending on the application) ***Band Pass*** (BP) **duplexer**. *This means that* deep attenuation 'notches' are provided for 1) receiver protection (from the transmitter's output) *as well as* 2) transmitter noise (at the receive frequency) as can be seen in the photo below where the two 'notches' appear in the 'noise'.

The benefits of BR duplexer designs are:

1. *reduced insertion loss* **-** lower IL values can be obtained than those of a BP design *given* the same 'Q' and number of resonators using either 'cavities' or stubs and
2. **BR duplexers are more suitable for close spacing 'splits'** (repeater splits) when working with a small number of Q-limited (non-optimum Q value) resonant elements such as 1 1/4" or 1 5/8" Heliax Stubs.

1 5/8" Heliax stubs are *no substitute for* 3" or 5" diameter cavities in narrow-spaced repeater operation (as on **2 Meters**) *if* low insertion loss is desired. As it turns out though, with proper design Heliax stubs *are* suitable for use as 'stubs' (sometimes loosely called 'cavities') in a ***BR duplexer* design on the 2 Meter band.**

A *Band Pass* (BP) duplexer *can* be implemented using Heliax stubs (the same type of stubs as described on this page, stubs that nominally exhibit a deep 'notch' at one frequency) in a *Hybrid Ring Duplexer* configuration. Alas, simulations show that higher *insertion losses* result at each of the two 'pass frequencies' in a Hybrid Ring Duplexer using stubs whose Q is in the range of that obtainable from 1 5/8" Heliax. At present I don't have any details regarding *Hybrid Ring duplexers* other than this mention on this page.

-- Duplexer Requirements --

A duplexer must provide one basic thing: *Adequate isolation* between a receiver and transmitter to allow simultaneous operation of both, often described as 'duplex' or 'full duplex' operation. A duplexer accomplishes this by providing 'isolation' at basically two frequencies: the receive frequency and the transmit frequency. This isolation or *filtering* must address two main 'energy' components output by the transmitter, as well as couple both the receiver and the transmitter to the antenna with minimum practical insertion loss.

The two main 'energy' components output by the transmitter are:

> a) the transmit carrier (at the transmit frequency) at a power level of between 25 and 100 Watts, and
> b) transmitter *noise* that appears at the *receive* frequency.

The duplexer must reduce both of these 'energy' components to levels that:

> a) do not 'block' or 'overpower' the receiver (like the transmit carrier can do without a duplexer) and
> b) do not obscure, 'cover' or mask weak, microvolt-level signals intended to be picked up by the receiver.

60 Watt Transmitter Noise and Carrier budget

Perusing some Motorola and General Electric 2-way radio service manuals I find that most commercial radios specify the "spurious and harmonic" energy levels as being "85 dB below the (transmit) carrier". That means that any energy, other than the carrier itself, will be at least 85 dB weaker than the transmit carrier.

The following chart shows the signal environment a 60 Watt transmitter and it's corresponding noise spec can create using three different duplexer Isolation values (80, 85 and 90 dB). Additionally, the performance figures for the 60 Watt transmitter are shown for transmitter 'spurious and harmonic' noise specifications of 80 dB and 85 dB just to give us some room to see what 5 dB worse performance gives us.

	Dup Attn	Xmt noise	Atn Noise	Xmtr Level	Rcvr Noise
Power W	dB	dB down	uV rms	dBm	dBm
60	80	80	0.55	-32	-112
60	85	80	0.31	-37	-117
60	90	80	0.17	-42	-122
60	80	85	0.31	-32	-117
60	85	85	0.17	-37	-122
60	90	85	0.10	-42	-127

The chart above (and below) uses the following abbreviations:

Dup Attn, dB	- Duplexer attenuation or Isolation value. Isolation values of 80, 85 and 90 dB are shown in this chart.
Xmt noise, dB down	- Transmit noise, in dB down per transmitter specification, two groups here, 80 and 85 dB.
Atn Noise, uV rms	- Attenuated Noise in microvolts rms on receiver frequency.

Xmtr Level, dBm	- Transmitter signal level, in dBm, as seen at receiver port of the duplexer.
Rcvr Noise, dBm	- Receiver Noise level in dBm (rather than microvolts as the Atn Noise column shows).

For instance, for a 60 W transmitter with an 85 dB 'spurious and harmonic' specification, a duplexer with an 85 dB 'Isolation' value should show only .17 uV rms of transmitter noise at the receive port and the transmit carrier level will be at -37 dBm.

100 Watt Transmitter Noise and Carrier budget

	Dup Attn	Xmt noise	Atn Noise	Xmtr Level	Rcvr Noise
Power W	dB	dB down	uV rms	dBm	dBm
100	80	80	0.71	-30	-110
100	85	80	0.40	-35	-115
100	90	80	0.22	-40	-120
100	80	85	0.40	-30	-115
100	85	85	0.22	-35	-120
100	90	85	0.13	-40	-125

For a 100 W transmitter with an 85 dB 'spurious and harmonic' specification, a duplexer with a 90 dB Isolation value should show only .13 uV rms of transmitter noise at the receive port and the transmit carrier level at the receive port will be -40 dBm.

-- Duplexer Specs --

Duplexer performance can be measured and quantified with three main figures:

1) Insertion Loss,
2) Isolation (TX and RX Isolation) and
3) Return Loss.

I prefer using the term ***return loss*** to SWR or VSWR since so very few of us actually measure 'VSWR' directly; usually, we measure *return loss* using a directional coupler (or a directional Watt meter like the famous Bird 43 series) and convert this figure to VSWR using the usual, well-established formulas with a hand-held electronic calculator, via HP's APPCAD utility or using the venerable HP VSWR "Reflectometer" slide rule.

To that end, the following close relationships exist between Return Loss and VSWR:

Return Loss	VSWR
14 dB	1.5:1
18 dB	1.3:1
21 dB	1.2:1
26 dB	1.1:1

Insertion Loss

This value is the *measured loss* in the ***pass band*** of the receiver (or transmitter) leg between the receiver (or transmitter) port and the antenna port at the respective receive (or transmit) frequency. This value represents the small amount of ***attenuation*** or 'insertion loss' that results when the duplexer is placed in-line between the receiver or transmitter.

The following chart shows the reduction in *transmit power* due to the ***Insertion Loss*** of the duplexer. A 600 KHz split, 95 dB notch duplexer, properly designed and built, paying particular attention to the key physical parameters that determine the recovery from the 'deep' attenuation notch are capable of achieving insertion loss values of around 2 dB.

dB Insertion Loss and power out for 100W transmitter	dB	W	dB	W	dB	W	dB	W
	0.7	85	1.1	78	1.5	71	1.9	65
	0.8	83	1.2	76	1.6	69	2.0	63
	0.9	81	1.3	74	1.7	68	2.1	62
	1.0	79	1.4	72	1.8	66	2.2	60

Isolation

This value is the measured ***isolation*** between the Transmit port (port 3) and the Receive port (port 2); on this web page in S-Parameter parlance this is the *S23* value.

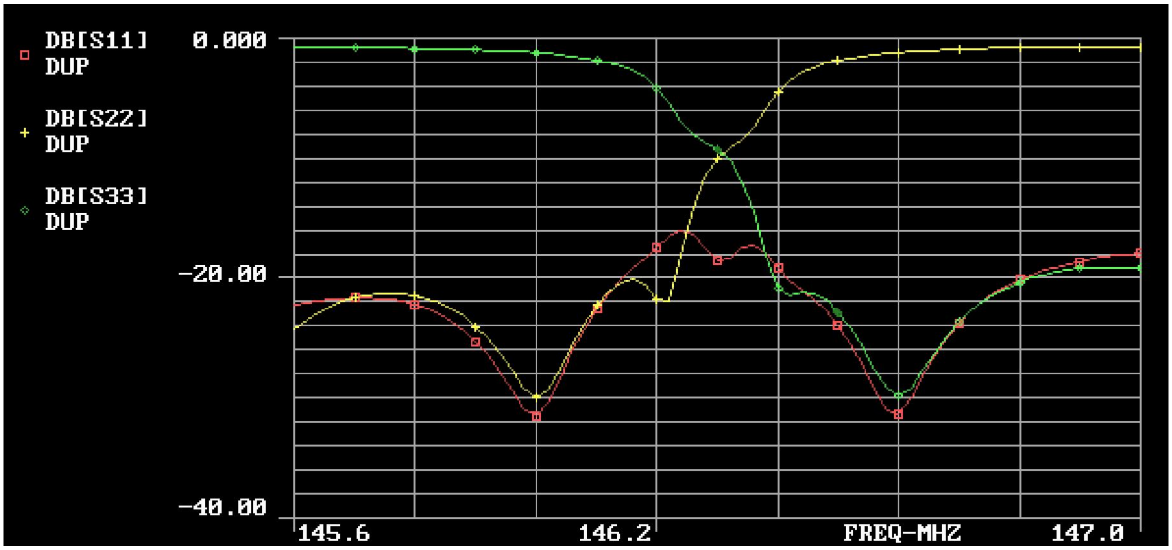
The 'Isolation' figure reveals the amount of isolation between the transmitter and the receiver. Two such 'values' for isolation exist for every duplexer, one for the receive frequency and one for the transmit frequency. Normally these two values are engineered to be the same, but, they can be different.

The chart below shows four different duplexer designs engineered for *four different Isolation values*; nominally 90, 95, 102 and 115 dB. The associated Insertion Loss values (under the S21 and S31 column headings) vary accordingly.

Stubs: LDF7	Freq	S21	S31	S23	Watts
Coax: RG-8	146.000	1.70 dB	87.6 dB	88.7 dB	
Perc: 94%	146.600	87.7 dB	1.67 dB	88.9 dB	68
Coax: RG-8	146.000	1.96 dB	94.3 dB	96.0 dB	
Perc: 93.5%	146.600	94.6 dB	1.88 dB	96.1 dB	65
Coax: RG-8	146.000	2.22 dB	100.8 dB	102.6 dB	
Perc: 93%	146.600	100.4 dB	2.14 dB	102.2 dB	60
Coax: RG-8	146.000	2.79 dB	111.7 dB	114.5 dB	
Perc: 92%	146.600	111.8 dB	2.76 dB	114.5 dB	<56

Return Loss (VSWR)

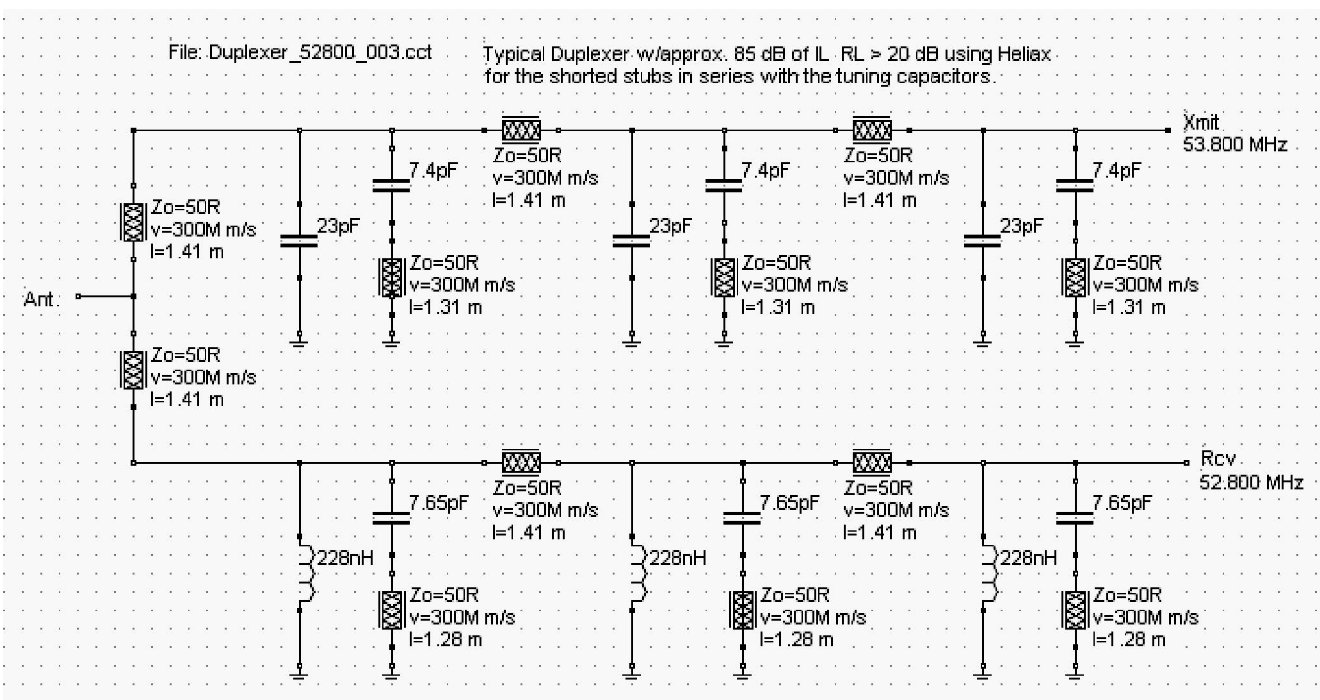
The *return loss* value, directly related to the VSWR (Voltage Standing Wave Ratio), is a measure of the *match* the duplexer presents to the transmitter, the receiver, and even the antenna. Below is the sweep obtained during modeling of a Heliax duplexer design. Practical experience shows that comparable results can be achieved when building the Heliax duplexer.



Sketches, Images

Schematic diagram of typical duplexer

Note: a) nominal component values are shown b) exact component values vary with design c) individual designs require tuning with RF instruments, d) lengths of transmission lines are in meters, e) receive and transmit frequencies are as indicated.



Duplexer design, website issues, or to have a duplexer built for use on your repeater or **e-mail Jim** (call sign: WB5WPA) at "**jvpoll at dallas -dot- net**" (Be sure to remove the at and -dot- and spaces and replace as required).

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